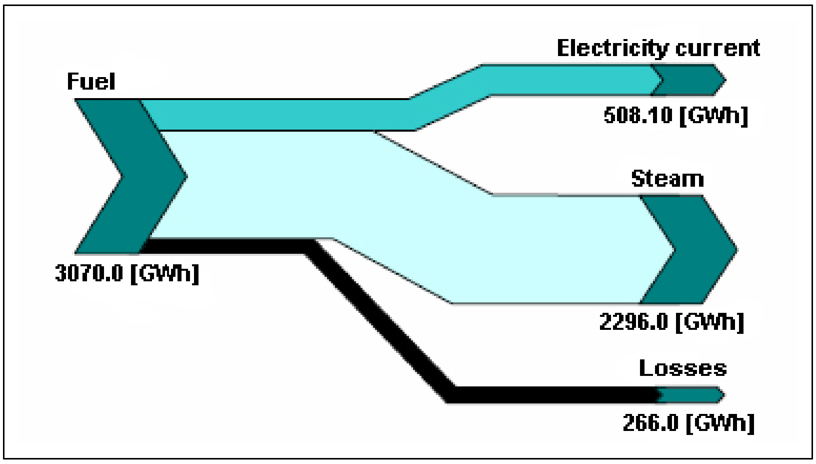
EUROPEAN COMMISSION
DIRECTORATE-GENERAL JRC
JOINT RESEARCH CENTRE
Institute for Prospective Technological Studies
**Competitiveness and Sustainability Unit**
**European IPPC Bureau**

## Integrated Pollution Prevention and Control

## Draft Reference Document on Best Available Techniques in the

# Energy Efficiency

## Draft July 2007



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This document is one of a series of foreseen documents as below (at the time of writing, not all documents have been drafted):

| **Reference Document on Best Available Techniques . . .** | **Code** |
|---|---|
| Large Combustion Plants | LCP |
| Mineral Oil and Gas Refineries | REF |
| Production of Iron and Steel | I&S |
| Ferrous Metals Processing Industry | FMP |
| Non Ferrous Metals Industries | NFM |
| Smitheries and Foundries Industry | SF |
| Surface Treatment of Metals and Plastics | STM |
| Cement and Lime Manufacturing Industries | CL |
| Glass Manufacturing Industry | GLS |
| Ceramic Manufacturing Industry | CER |
| Large Volume Organic Chemical Industry | LVOC |
| Manufacture of Organic Fine Chemicals | OFC |
| Production of Polymers | POL |
| Chlor – Alkali Manufacturing Industry | CAK |
| Large Volume Inorganic Chemicals - Ammonia, Acids and Fertilisers Industries | LVIC-AAF |
| Large Volume Inorganic Chemicals - Solid and Others industry | LVIC-S |
| Production of Speciality Inorganic Chemicals | SIC |
| Common Waste Water and Waste Gas Treatment/Management Systems in the Chemical Sector | CWW |
| Waste Treatments Industries | WT |
| Waste Incineration | WI |
| Management of Tailings and Waste-Rock in Mining Activities | MTWR |
| Pulp and Paper Industry | PP |
| Textiles Industry | TXT |
| Tanning of Hides and Skins | TAN |
| Slaughterhouses and Animals By-products Industries | SA |
| Food, Drink and Milk Industries | FDM |
| Intensive Rearing of Poultry and Pigs | ILF |
| Surface Treatment Using Organic Solvents | STS |
| Industrial Cooling Systems | CV |
| Emissions from Storage | ESB |
| **Reference Document . . .** | |
| General Principles of Monitoring | MON |
| Economics and Cross-Media Effects | ECM |
| *Energy Efficiency Techniques* | *ENE* |

# EXECUTIVE SUMMARY

# PREFACE

## 1. Status of this document

Unless otherwise stated, references to 'the Directive' in this document means the Council Directive 96/61/EC on integrated pollution prevention and control as amended by Directive 2003/87/EC. As the Directive applies without prejudice to Community provisions on health and safety at the workplace, so does this document.

This document is a working draft of the European IPPC Bureau. It is not an official publication of the European Communities and does not necessarily reflect the position of the European Commission.

## 2. Mandate of the work

In addition, this document is specifically mandated by a special request from the Commission Communication on the implementation of the European Climate Change Programme (COM(2001)580 final) ECCP concerning energy efficiency in industrial installations. The ECCP asked that effective implementation of the energy efficiency provisions of the IPPC Directive are promoted and that a special horizontal BREF (BAT reference document) addressing generic energy efficiency techniques should be prepared.

## 3. Relevant legal obligations of the IPPC Directive and the definition of BAT

In order to help the reader understand the legal context in which this document has been drafted, some of the most relevant provisions of the IPPC Directive are described in this preface, including the definition of the term 'best available techniques'. This description is inevitably incomplete and is given for information only. It has no legal value and does not in any way alter or prejudice the actual provisions of the Directive.

The purpose of the Directive is to achieve integrated prevention and control of pollution arising from the activities listed in its Annex I, leading to a high level of protection of the environment as a whole including energy efficiency and the prudent management of natural resources. The legal basis of the Directive relates to environmental protection. Its implementation should also take account of other Community objectives such as the competitiveness of the Community's industry and the decoupling of growth from energy consumption thereby contributing to sustainable development. The Scope gives further information on the legal basis of energy efficiency in the Directive.

More specifically, the Directive provides for a permitting system for certain categories of industrial installations requiring both operators and regulators to take an integrated, overall view of the potential of the installation to consume and pollute. The overall aim of such an integrated approach must be to improve the design and construction, management and control of industrial processes so as to ensure a high level of protection for the environment as a whole. Central to this approach is the general principle given in Article 3 that operators should take all appropriate preventative measures against pollution, in particular through the application of best available techniques, enabling them to improve their environmental performance including energy efficiency.

The term "best available techniques" is defined in Article 2(11) of the Directive as "the most effective and advanced stage in the development of activities and their methods of operation which indicate the practical suitability of particular techniques for providing in principle the basis for emission limit values designed to prevent and, where that is not practicable, generally to reduce emissions and the impact on the environment as a whole." Article 2(11) goes on to clarify further this definition as follows:

"techniques" includes both the technology used and the way in which the installation is designed, built, maintained, operated and decommissioned;

"available" techniques are those developed on a scale which allows implementation in the relevant industrial sector, under economically and technically viable conditions, taking into consideration the costs and advantages, whether or not the techniques are used or produced inside the Member State in question, as long as they are reasonably accessible to the operator;

"best" means most effective in achieving a high general level of protection of the environment as a whole.

Furthermore, Annex IV of the Directive contains a list of "considerations to be taken into account generally or in specific cases when determining best available techniques bearing in mind the likely costs and benefits of a measure and the principles of precaution and prevention". These considerations include the information published by the Commission pursuant to Article 16(2).

Competent authorities responsible for issuing permits are required to take account of the general principles set out in Article 3 when determining the conditions of the permit. These conditions must include emission limit values, supplemented or replaced where appropriate by equivalent parameters or technical measures. According to Article 9(4) of the Directive:

*(without prejudice to compliance with environmental quality standards), the emission limit values, equivalent parameters and technical measures shall be based on the best available techniques, without prescribing the use of any technique or specific technology, but taking into account the technical characteristics of the installation concerned, its geographical location and the local environmental conditions. In all circumstances, the conditions of the permit shall include provisions on the minimisation of long-distance or transboundary pollution and must ensure a high level of protection for the environment as a whole.*

Member States have the obligation, according to Article 11 of the Directive, to ensure that competent authorities follow or are informed of developments in best available techniques.

## 4. Objective of this document

This document gives general advice how to implement the requirements of the Directive set out in (3) above.

Article 16(2) of the Directive requires the Commission to organise 'an exchange of information between Member States and the industries concerned on best available techniques, associated monitoring and developments in them', and to publish the results of the exchange.

The purpose of the information exchange is given in recital 25 of the Directive, which states that 'the development and exchange of information at Community level about best available techniques will help to redress the technological imbalances in the Community, will promote the worldwide dissemination of limit values and techniques used in the Community and will help the Member States in the efficient implementation of this Directive.'

The Commission (Environment DG) established an information exchange forum (IEF) to assist the work under Article 16(2) and a number of technical working groups have been established under the umbrella of the IEF. Both IEF and the technical working groups include representation from Member States and industry as required in Article 16(2).

The aim of this series of documents is to reflect accurately the exchange of information which has taken place as required by Article 16(2) and to provide reference information for the permitting authority to take into account when determining permit conditions. By providing relevant information concerning best available techniques, these documents should act as valuable tools to drive environmental performance including energy efficiency.

## 5. Information Sources

This document represents a summary of information collected from a number of sources, in particular, through the expertise of the groups established to assist the Commission in its work, and verified by the Commission services. The work of the contributors and the expert groups is gratefully acknowledged.

## 6. How to understand and use this document

The information provided in this document is intended to be used as an input to the determination of BAT for energy efficiency in specific cases. When determining BAT and setting BAT-based permit conditions, account should always be taken of the overall goal to achieve a high level of protection for the environment as a whole including energy efficiency.

The rest of this section describes the type of information that is provided in each section of this document.

Chapter 1 provides an introduction to terms and concepts in energy and thermodynamics. It describes definitions of energy efficiency for industry, how to develop and define indicators to monitor energy efficiency, and the importance of defining boundaries for installations, and component systems and/or units.

Chapters 2 and 3 describe in more detail the energy efficiency techniques that are found in more than one industry sector and that are considered to be most relevant for determining BAT and BAT-based permit conditions:

- Chapter 2 describes techniques to be considered at the level of the entire installation
- Chapter 3 describes techniques to be considered for specific systems and equipment that use significant energy and are commonly found within installations.

This information includes some idea of the energy efficiency that can be achieved, the costs and the cross-media issues associated with the technique, and the extent to which the technique is applicable to the range of installations requiring IPPC permits, for example new, existing, large or small installations.

Chapter 4 presents the techniques that are considered to be compatible with BAT in a general sense. The purpose is to provide general indications about energy efficiency techniques that can be considered as an appropriate reference point to assist in the determination of BAT-based permit conditions or for the establishment of general binding rules under Article 9(8). It should be stressed, however, that this document does not propose energy efficiency values for permits. The determination of appropriate permit conditions will involve taking account of local, site-specific factors such as the technical characteristics of the installation concerned, its geographical location and the local environmental conditions. In the case of existing installations, the economic and technical viability of upgrading them also needs to be taken into account. Even the single objective of ensuring a high level of protection for the environment as a whole will often involve making trade-off judgements between different types of environmental impact, and these judgements will often be influenced by local considerations.

Chapter 5 provides additional information on policy and financial incentives, and other techniques that may be considered by the operator in assisting the implementation of energy saving measures for the business as a whole.

Although an attempt is made to address some of these issues, it is not possible for them to be considered fully in this document. The techniques presented in Chapter 4 will therefore not necessarily be appropriate for all installations. On the other hand, the obligation to ensure a high level of environmental protection including the minimisation of long-distance or transboundary pollution implies that permit conditions cannot be set on the basis of purely local considerations. It is therefore of the utmost importance that the information contained in this document is fully taken into account by permitting authorities

Since the best available techniques change over time, this document will be reviewed and updated as appropriate. All comments and suggestions should be made to the European IPPC Bureau at the Institute for Prospective Technological Studies at the following address:

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# Best Available Techniques Reference Document on Energy Efficiency

# List of figures

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# SCOPE

This document together with other BREFs in the series (see list on the reverse of the title page), are intended to cover the energy efficiency issues under the IPPC Directive. Energy efficiency is not restricted to any one industry sector mentioned in Annex 1 to the Directive as such, but is a horizontal issue which is required to be taken into account in all cases (as described below). In the Directive there are direct and indirect references to energy and energy efficiency in the following recitals and articles (in the order they appear in the Directive):

- (Recital) 1. Whereas the objectives and principles of the Community's environment policy, as set out in Article 130r of the Treaty, consist in particular of preventing, reducing and as far as possible eliminating pollution by giving priority to intervention at source and **ensuring prudent management of natural resources**, in compliance with the 'polluter pays' principle and the principle of pollution prevention; *(generally, most energy in Europe is derived from non-renewable natural resources)*

- (Recital) 2. Whereas the Fifth Environmental Action Programme, … in the resolution of 1 February 1993 on a Community programme of policy and action in relation to the environment and sustainable development (4), accords **priority to integrated pollution control as an important part of the move towards a more sustainable balance between human activity and socio-economic development, on the one hand, and the resources and regenerative capacity of nature, on the other;**

- Article 2(2): 'pollution' shall mean the direct or indirect introduction of…vibrations, **heat** or noise which may be harmful to human health or the quality of the environment… *(vibration, heat and noise are all manifestations of energy)*

- Article 3: Member States shall take the necessary measures to provide that the competent authorities ensure that installations are operated in such a way that: … … (d) **energy is used efficiently**

- Article 6.1: Member States shall take the necessary measures to ensure that an application to the competent authority for a permit includes a description of:
  - — the raw and auxiliary materials, other substances **and the energy used in, or generated by**, the installation

- Article 9.1: Member States shall ensure that the permit includes all measures necessary for compliance with the requirements of Articles 3 and 10 **(which includes energy efficiency, see (b) above)**

- Annex IV (item 9). One of the issues to be taken into account in determining BAT generally or specifically is the consumption and nature of raw materials (including water) used in the process **and their energy efficiency**.

The IPPC Directive has been amended by Council Directive 2003/87/EC of 13 October 2003 establishing a scheme for greenhouse gas emission allowance trading within the Community (the ETS Directive):

- Article 9(3): For activities listed in Annex 1 to Directive 2003/87/EC Member States may choose **not to impose requirements relating to energy efficiency** in respect of **combustion units or other units emitting carbon dioxide** on the site.

Energy efficiency is a priority issue within the European Union and this document on energy efficiency has links to other Commission policy and legal instruments. The key examples are:

Policy instruments:

- the Berlin Declaration March 2007
- the Energy Efficiency Action Plan October 2007 COM(2006)545 FINAL
- the Green Paper on Energy Efficiency COM(2005)265 final of 22 June 2005
- Commission Communication on the implementation of the European Climate Change Programme (COM(2001)580 final) ECCP concerning energy efficiency in industrial installations (specifically mandating this document, see Preface)
- the Green Paper Towards a European strategy for the security of energy supply (COM(2000) 769 final) of 29 November 2000

Legal instruments:

- Council Directive 2004/8/EC of 11 February 2004 on the promotion of cogeneration based on a useful heat demand in the internal energy market and amending Directive 92/42/EEC
- Council Directive 2006/32/EC of 5 April 2006 on energy end-use efficiency and energy services and repealing Council Directive 93/76/EEC
- the framework Directive for the setting of eco-design requirements for energy using products, EuP (2005/32/EC)

Other tools for policy implementation:

- an Energy Efficiency Toolkit for SMEs developed in the framework of the EMAS Regulation
- studies and projects under the umbrella Intelligent Energy – Europe and SAVE, which deal with energy efficiency in buildings and industry.

This document also interfaces with the BREFs for specific industries sectors (‘vertical BREFs’), in particular the BREF for Large Combustion Plants (LCP, where energy efficiency is a major topic). It also interfaces with the BREFs for industrial cooling systems (CVV) and common waste water and waste gas treatment (CWW) (‘horizontal’ BREFs, applicable to more than one sector).

**Energy efficiency in this document**

The policy statements place energy policy (including reduction of use) and climate protection (specifically, reducing the impact of combustion gases) among the top priorities of the European Union.

The amended IPPC Directive (including the amendments for the Aarhus convention and the ETS Directive) still requires the efficient use of energy as one of its general principles.

For activities listed in Annex I to Directive 2003/87/EC (see below), Member States may only choose not to impose energy efficiency requirements in respect of combustion units or other units directly emitting carbon dioxide. This flexibility does not apply to units not directly emitting carbon dioxide within the same installation.

| **Categories of activities in Annex 1 to Directive 2003/87/EC** |
|---|
| *Note 2 to Annex 1:* The threshold values given below generally refer to production capacities or outputs. Where one operator carries out several activities falling under the same subheading in the same installation or on the same site, the capacities of such activities are added together |
| *Energy activities*<br>Combustion installations with a rated thermal input exceeding 20 MW (except hazardous or municipal waste installations)<br>Mineral oil refineries<br>Coke ovens |
| *Production and processing of ferrous metals*<br>Metal ore (including sulphide ore) roasting or sintering installations<br>Installations for the production of pig iron or steel (primary or secondary fusion) including continuous casting, with a capacity exceeding 2.5 tonnes per hour |
| *Mineral industry*<br>Installations for the production of cement clinker in rotary kilns with a production capacity exceeding 500 tonnes per day or lime in rotary kilns with a production capacity exceeding 50 tonnes per day or in other furnaces with a production capacity exceeding 50 tonnes per day<br>Installations for the manufacture of glass including glass fibre with a melting capacity exceeding 20 tonnes per day<br>Installations for the manufacture of ceramic products by firing, in particular roofing tiles, bricks, refractory bricks, tiles, stoneware or porcelain, with a production capacity exceeding 75 tonnes per day, and/or with a kiln capacity exceeding 4 $m^3$ and with a setting density per kiln exceeding 300 $kg/m^3$ |
| *Other activities*<br>Industrial plants for the production of<br>(a) pulp from timber or other fibrous materials<br>(b) paper and board with a production capacity exceeding 20 tonnes per day |

This document therefore contains guidance on energy efficiency for all IPPC installations (and their component units) not listed in Annex I to Directive 2003/87/EC, and to:

- units not directly emitting $CO_2$ in those installations listed in Annex I to Directive 2003/87/EC
- units directly emitting $CO_2$ in those installations listed in Annex I to Directive 2003/87/EC, with the option for the Member States to impose them or not.

This guidance in this document may also be useful to operators and industries not within the scope of IPPC.

The IPPC Directive is concerned with the activities defined in its own Annex 1, and those directly associated activities with technical connections. It is not concerned with products. Energy efficiency in this context therefore excludes any consideration of the energy efficiency of products, including where the increased use of energy in the installation may contribute to a more energy efficient product. (For example, where extra energy is used to make a higher strength steel, which may enable less steel to be used in car construction and result in fuel savings). Some good practice measures that can be applied by the operator but are outside of the cope of IPPC permitting, e.g. transport, are discussed (see Chapter 5).

The efficient use of energy and the decoupling of energy use from growth is a key aim of sustainability policies. The IPPC Directive considers energy as a resource and requires it to be used efficiently, without specifying the source of the energy. This document therefore considers energy efficiency in terms of all energy sources and their use within the installation to provide products or services. It does not consider the use of secondary fuels or renewable energy sources as an improvement in energy efficiency. The replacement of fossil fuels by other options (and the net decrease in $CO_2$ emissions) is an important issue, but is dealt with elsewhere.

Some references use the term 'energy efficiency management' and others 'energy management'. In this document, (unless stated otherwise) both terms are taken to mean the achievement of the efficient use of physical energy. Both terms can also mean the management of energy costs: normally, reducing the physical quantity of energy used results in reducing costs. However, there are techniques for managing the use of energy (particularly reducing the peak demands) to stay within the lower bands of the suppliers' tariff structure, and reduce costs, without necessarily reducing the overall energy consumption. These techniques are not considered part of energy efficiency as defined in the IPPC Directive.

This document has been elaborated after the first version of all other BREFs. It is therefore intended that it will serve as a reference on energy efficiency for the revision of the BREFs (see the Mandate in the Preface).

## Energy efficiency issues covered by this document

| **Chapter** | **Issues** |
|---|---|
| 1 | Introduction and definitions |
| 1.1 | Introduction to energy efficiency in the EU and this document. |
|  | Economics and cross-media issues (which are covered in more detail in the ECM BREF) |
| 1.2 | Terms used in energy efficiency, e.g. energy, work, power and an introduction to the laws of thermodynamics |
| 1.3 | Energy efficiency indicators and their use |
|  | The importance of defining units, systems and boundaries |
|  | Other related terms, e.g. primary and secondary energies, heating values, etc. |
| 1.4 | Using energy efficiency indicators in industry from a top down, whole site approach and the problems encountered |
| 1.5 | Energy efficiency from a bottom-up approach and the problems encountered |
|  | The importance of a systems approach to improving energy efficiency |
|  | Important issues related to defining energy efficiency |
| 2 | Techniques to consider in achieving energy efficiency at an installation level |
|  | The importance of taking a strategic view of the whole site, setting targets and planning actions before investing (further) resources in energy-saving activities |
| 2.1 | Energy efficiency management through specific or existing management systems |
| 2.2 | Planning and establishing objectives and targets through:<br>• continuous environmental improvement<br>• top-down consideration of the installation and its component systems<br>• considering energy efficiency at the design stage for new or upgraded plant<br>• selecting energy efficient process technologies<br>• increasing process integration between processes, systems and plants<br>• maintaining the impetus of energy efficiency initiatives |
| 2.3 | Maintaining sufficient expertise at all levels to deliver energy efficient systems, not just in energy management, but in expert knowledge of the processes and systems |
| 2.4 | Effective process control: ensuring that processes are run as efficiently as possible, for greater energy efficiency, minimising off-specification products, etc. |

| | |
|---|---|
| 2.5 | The importance of planned maintenance and rapid attention to unscheduled repairs, which waste energy, such as steam and compressed air leaks. |
| 2.6 | Monitoring and measuring are essential issues, including:<br>• qualitative techniques<br>• quantitative measurements, using direct metering and advanced metering systems<br>• applying new generation flow-metering devices<br>• using energy models, databases and balances<br>• optimising utilities using advanced metering and software controls |
| 2.7 | Energy auditing is an essential technique to identify areas of energy usage, possibilities for energy saving, and checking the results of actions taken |
| 2.8 | Pinch technology is a useful tool where heating and cooling streams exist in a site, to establish the possibilities of integrating energy exchange |
| 2.9 | Exergy and enthalpy analysis are useful tools to assess the possibility of saving energy and whether the surplus energy can be used |
| 2.9 | Sankey diagrams help the analysis and explanation of energy vectors |
| 2.10 | Benchmarking is a vital tool in assessing the performance of an installation, process or system, by verifying against external or internal energy usage levels or energy efficient methods |
| 2.11 | EMAT (energy manager's tool) assists energy managers to quantify the energy savings of various horizontal technologies |
| 3 | Techniques to consider in achieving energy efficiency at a system level, and at a component parts level. This discusses the techniques to consider when optimising systems, and techniques for equipment that has not been optimised as part of a system review |
| 3.1 | The main combustion techniques are discussed in the LCP BREF. In this document, key techniques are highlighted |
| 3.2 | Steam systems |
| 3.3 | Waste heat recovery by using heat exchangers and heat pumps |
| 3.4 | The main types of cogeneration are explained, as well as tri-generation and the use of tri-generation in district heating and cooling |
| 3.5 | The way electrical power is used in an installation can result in energy inefficiencies in the internal and external supply systems |
| 3.6 | Electric motor-driven sub-systems are discussed in general, although specific systems are discussed in more detail (see 3.7 and 3.8) |
| 3.7 | The use and optimisation of compressed air systems (CAS) |
| 3.8 | Pumping systems and their optimisation |
| 3.9 | Drying and separation processes and their optimisation |
| 3.10 | Lighting and its optimisation |
| *N.B* | *Cooling systems are discussed in the CV BREF* |
| 4 | Conclusions on energy efficiency techniques |
| 5 | There are techniques and policy incentives that can assist the implementation of energy efficiency and energy cost-saving that do not form part of a permit. Some information has been provided as part of the information exchange, and is included in this chapter. These include national incentives such as financially assisting energy efficiency measures, tax breaks, etc. and industry initiatives such as out-sourcing the provision of energy-related utilities (ESCOs).<br><br>Also, information for operators may wish to optimise other non-installation activities, such as transport. |
| Annexes | Additional data and more detailed examples. |

## The boundary of this document with other BREFs

This document gives:

- horizontal guidance on energy efficiency to all the activities in Annex 1 to the IPPC Directive
- references to BREFs where particular techniques for energy efficiency have already been discussed in detail, and can be applied to other sectors. For example:
    - the LCP BREF discusses energy efficiency relating to combustion and points out that these techniques may be applied to combustion plant with a capacity below 50 MW
    - the CV BREF (industrial cooling systems)
- More information on techniques that can be found in other BREFs, where this is thought to be helpful (e.g. the OFC and SIC BREFs already include Pinch Technology.

This document does not:

- include information specific to sectors covered by other BREFs. For example:
    - the WI BREF discusses energy efficiency techniques for waste incinerators
    - the STM BREF discusses the energy efficiency of electroplating solutions
- derive sector-specific BAT.

However, a summary of sector-specific BAT from other BREFs are included in Annex 13 for information.

This document provides general guidance, and therefore may also provide information useful to other industries not covered by the IPPC Directive.

# 1 INTRODUCTION AND DEFINITION

[3, FEAD and Industry, 2005] [97, Kreith, 1997] [127, TWG, , 145, EC, 2000]

## 1.1 Introduction

### 1.1.1 Energy in the EU industrial sector

*'We intend jointly to lead the way in energy policy and climate protection and make our contribution to averting the global threat of climate change.'* Berlin Declaration (25 March 2007)

Energy use in the EU-15 industrial sector in 1998 was 262 Mtoe (million tonnes of oil equivalent, or 11 004 PJ) or around 28 % of the annual EU final energy use. This is forecast to rise to 290 Mtoe by 2020. Electricity and heat production represent 8 % and 18.6 % respectively. The two most energy intensive users are the iron and steel and chemical industries which consume 20 % and 16.3 % of industrial energy use respectively. Around 25 % of electricity used by industry is produced by industry itself. Figure 1.1 shows the largest energy consuming industries in the EU, which are all covered by the IPPC Directive According to the EPER, the main IPPC emitters account for about 40 % of all European $CO_2$ emissions, about 70 % of all $SO_x$ emissions and about 25 % of all $NO_X$ emissions.[145, EC, 2000, 152, EC, 2003].

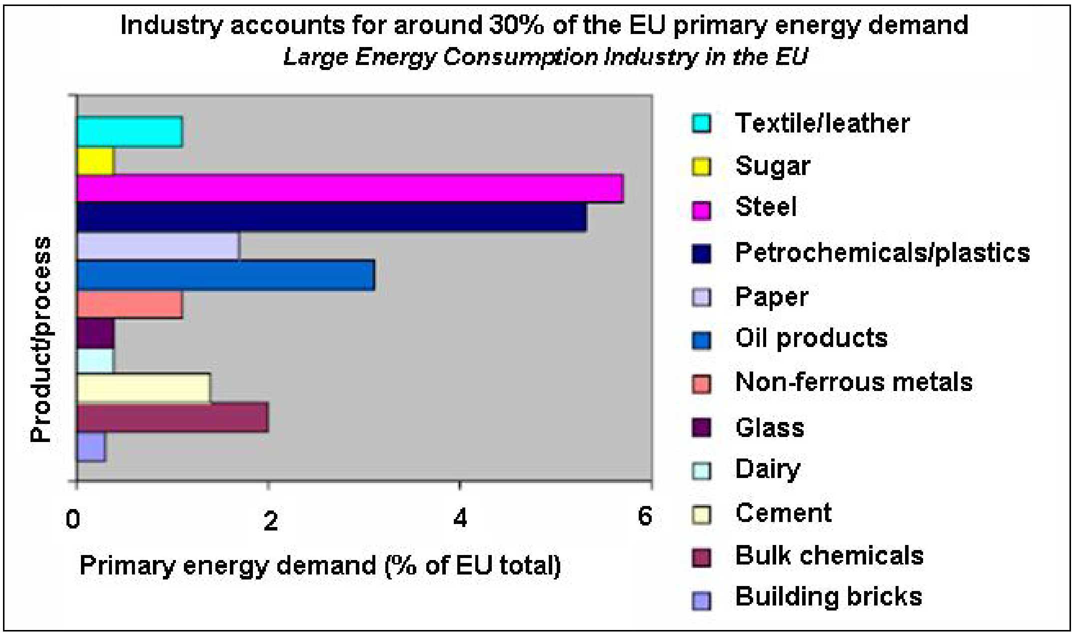
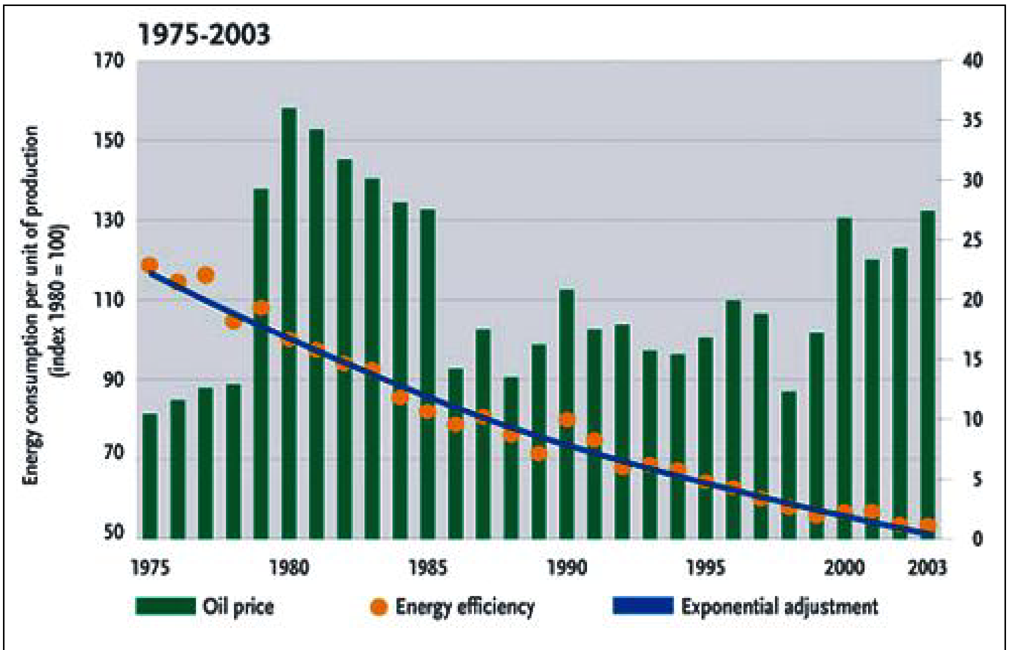


**Figure 1.1: Percentage of EU primary energy demand used by process industries**
[145, EC, 2000]

According to numerous studies [145, EC, 2000], the EU could save at least 20 % of its present energy consumption in a cost-effective manner, equivalent to EUR 60 billion per year, or the present combined energy consumption of Germany and Finland [European Commission Green Paper on Energy Efficiency (COM(2005) final of June 2005)]. This paper also points out that energy saving is without doubt the quickest, most effective and most cost-effective way to reduce greenhouse gas emissions, as well as improving air quality. Energy efficiency is also an important factor in the management of natural resources (in this case, energy sources) and sustainable development, and plays an important role in reducing European dependence on these resources. Such an efficiency initiative, although requiring considerable investments, would make a major contribution to the Lisbon objectives, by creating as many as a million new jobs and increasing competitiveness [145, EC, 2000, 152, EC, 2003].

Many sectors have considerably improved energy efficiency over the past 20 years. Dominant market drivers are productivity, product quality and new markets. EU energy efficiency legislation is recent (see the Preface), although legislation has existed for a longer period in certain Member States. The steps which industry has taken have largely been voluntary and usually driven by cost, but are also in conjunction with EU and MS initiatives (see Preface and Chapter 5). For example, the EU chemical industry is one of the biggest gas consumers among EU manufacturing industries, and energy represents 1 - 60 % of the production costs. However, the chemical industry's specific energy consumption has reduced by 55 % from 1975 to 2003.



Sources: Cefic, IEA and UN
Notes: Energy efficiency is measured by energy input per unit of chemicals production
* EU 15

Figure 1.2: Chemical industry energy usage 1975 – 2003

### 1.1.2 Energy efficiency and the IPPC Directive

The legal background to energy efficiency and this document is set out fully in the Preface and the Scope. The permit writer and operator should be aware of what using energy efficiently means, how it can be achieved, measured or assessed and therefore how it may be considered in a permit.

The industrial activities covered by IPPC are listed in Annex 1 to the IPPC Directive. Examples of IPPC production processes/units/sites are:

- a gas powered electricity plant takes in gas as its feedstock (input) and the product of this production process is electricity. The energy used is the energy available within the gas. Low grade heat energy is also generated (as well as the electricity), and this is usually lost in cooling. If it can be used (e.g. in a district heating scheme), then the specific energy efficiency is improved
- a refinery takes in crude oil and transforms this into gasoline, diesel, fuel oil and a number of other products. A part of these products is burned internally to provide the necessary energy for the conversion process. Usually, some electricity also needs to be imported, unless a cogeneration plant is installed within the refinery, in which case the refinery may become a net exporter of electricity
- a steam cracker takes in liquid and gaseous feeds from a refinery and converts these to ethylene and propylene, plus a number of by-products. Part of the energy consumed is generated internally in the process, supplemented by imports of steam, electricity and fuel
- the feeding to the rolling mill in a steel works consists of approximately 2 decimetres thick, flat steel plates that are to be rolled out into coil with a thickness of a few millimetres. The rolling mill consists of furnaces, rolling mill equipment, cooling equipment and support systems.
- a waste incinerator takes 150 000 t of waste left after material recycling and biological recovery from a population of 500 000. The incinerator can generate 60 000 MWh of electricity a year: of this, 15 000 MWh/yr are used internally and 45 000 MWh/yr are exported to the grid. This will supply the domestic electrical consumption of 60 000 inhabitants. Where there is demand for heat, high pressure steam is used to generate electricity and the remaining low or medium pressure steam is used by district heating or industry. It is more efficient to generate heat, and when heat is used, the electricity generated is less. If there is sufficient heat demand, the plant can be constructed to supply heat only. The supply and balance of electricity generated and heat produced depend on there being a use for the heat and other contract conditions
- an intensive poultry (broiler) rearing installation has places for 40 000 birds, and rears chicks to the required slaughter weight (in five to eight weeks). The units use energy in feeding and watering systems, lighting, moving manure and bedding and ventilation/heating/cooling. The manure is usually spread on land, but may be used as a feedstock in a biogas generation plant on- or off-site
- a publication gravure printing installation has five printing presses with 40 ink units, producing high quality magazine and catalogues. It uses electrical energy for the motors driving the presses, in compressed air and hydraulic systems used in the printing processes, natural gas for drying and steam for regenerating its toluene recovery system (using solvent absorption in the waste treatment system).

All IPPC installations have associated activities and supporting facilities using energy, such as systems for hydraulics, lubricating, compressed air, ventilation, heating, cooling and the constituent pumps, fans, motors etc. There are also maintenance workshops, staff areas, offices, changing rooms, store areas, etc. which will require heating or cooling, hot water, lighting etc.

### 1.1.3 Energy efficiency in integrated pollution prevention and control

Energy efficiency techniques are available from a wide variety of sources, and in many languages. This document considers key concepts and techniques in the perspective of *integrated pollution prevention and control* for the whole installation. The information exchange showed that while individual techniques can be applied and may save energy, it is by considering the whole site and its component systems strategically that major energy efficiency improvements can be made. For example, changing the electric motors in a compressed air system may save about 2 % of the energy input, whereas a complete review of the whole system could save up to 37 % (see Section 3.7). Indeed, concentrating on techniques at the constituent part level may be too prescriptive. In some cases this may prevent or delay decisions which have a greater environmental benefit, by utilising financial and other resources for investments that have not been optimised for energy efficiency.

Equally, in some cases, applying energy efficiency techniques at a component or system level may also maintain or increase cross-media effects (environmental disbenefits). An example would be an installation using organic solvents in surface treatment (coating). Individual components (e.g. motors) may be changed for more energy efficient ones, even the solvent extraction and waste gas treatment (WGT) system may be optimised to minimise energy usage, but a major environmental gain would be to change part or all of the process to be low-solvent or solvent-free (where this is technically applicable). In this case, the actual process may use more energy than the original coating process in drying or curing, but major energy savings would result from no longer requiring an extraction and WGT system. In addition, the overall solvent emissions from the site could be reduced (see Section 2.2.1 and the STS BREF).

**Detail of document layout**
The details of how the document is laid out are set out in the Scope.

The explanations and terms given in this chapter and other chapters are an introduction to the issues, and relate to IPPC- and other industries generally at a non-energy expert level. More extensive scientific information and explanation (as well as the mathematical formulae and derivations) can be found in standard textbooks or references on thermodynamics.

### 1.1.4 Economic and cross-media issues

Energy is the same as other valuable raw material resources required to run a business – and is not merely an overhead and part of business maintenance. Energy has costs and environmental impacts and needs to be managed well in order to increase the business' profitability and competitiveness, as well as to mitigate the seriousness of these impacts.

The Commission has indicated that it can be expected that process-integrated measures will generally have a positive or more or less neutral impact on the profitability of enterprises.[1] It is inevitable that some BAT will not have a payback, but their societal benefits outweigh the costs incurred, in keeping with the 'polluter pays' principle.

The determination of BAT involves an assessment of the estimated net costs of implementing a technique in relation to the environmental benefits achieved. A second economic test relates to whether the technique can be introduced in the relevant sector under economically viable conditions. This affordability test can be only legitimately applied at a European sector level[2] [152, EC, 2003]

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[1] COM(2003) 354 final states: 'End-of-pipe' measures often have a negative short term impact on profitability. However, no 'end-of-pipe' measures exist for energy efficiency; the nearest analogy is easy bolt-in replacements, such as motors. These may not achieve the best environmental and/or economic returns. See Section 1.5.1

[2] 'Sector' should be understood as a relatively high level of disaggregation, e.g. the sector producing chlorine and caustic soda rather than the whole chemical sector.

Energy efficiency has the advantage that measures to reduce the environmental impact usually have a financial payback. Where data has been included in the information exchange, costs are given for individual techniques in the following chapters (or are given in the relevant vertical sector BREFs). The issue often arises of cost-benefit, and the economic efficiency of any technique can provide information for assessing the cost-benefits. In the case of existing installations, the economic and technical viability of upgrading them needs to be taken into account. Even the single objective of ensuring a high level of protection for the environment as a whole will often involve making trade-off judgements between different types of environmental impact, and these judgements will often be influenced by local considerations (as noted in the Preface). For example, in some cases energy consumption may be increased to reduce other environmental impacts as a result of implementing IPPC (for instance, using waste gas treatment to reduce emissions to air).

In some cases, energy consumption may be increased to reduce other environmental impacts as a result of implementing IPPC (for instance, using waste gas treatment to reduce emissions to air).

These issues are discussed further in the ECM BREF.

## 1.2 Energy and the laws of thermodynamics

[2, Valero-Capilla, 2005, 153, Wikipedia], [3, FEAD and Industry, 2005], [97, Kreith, 1997] [154, Columbia_Encyclopedia]

### 1.2.1 Energy, heat, power and work

Energy is a natural phenomenon and is the ability or capacity to do work (this could also be described as producing change or ‘available energy’). Energy is measured in terms of this change of a ‘system’ from one state to another, measured in the SI system in joules. Energy can take a wide variety of forms and is named after the action (or work achieved by) a specific force. There are seven main forms of energy generally used in industry:

1. **Chemical energy** is the energy that bonds atoms or ions together. In industrial activities, it is stored in carbon-based fuels, and released by a chemical reaction (in this case oxidation, and usually by combustion, releasing carbon dioxide). The energy released is usually converted to more usable forms, such as to mechanical energy (e.g. combustion engines), or to thermal energy (e.g. direct process heating).

2. **Mechanical energy** is associated with motion (such as the expansion in the cylinders of internal combustion engines), and can be used directly to drive machines, e.g. cars, lorries, etc. It is also widely used to power generators to produce electrical energy. Mechanical energy includes **wave** and **tidal energy**.

3. **Thermal energy** is the internal motion of particles of matter. It can be regarded as either the thermodynamic energy (or internal energy), or as a synonym for heat. However, heat is in reality the action of transferring the thermal energy from one system (or object) to another. Thermal energy can be released by chemical reactions such as burning, nuclear reactions, resistance to electric current (as in electric stoves), or mechanical dissipation (such as friction).

4. **Electric energy** is the ability of electric forces to do work during rearrangements of positions of charges (e.g. when electric charge flows in a circuit). It is closely related to **magnetic energy** is a form of energy present in any electric field or magnetic field (volume containing electromagnetic radiation), often associated with movement of an electric charge. Electromagnetic radiation includes **light energies**.

5. **Nuclear energy** is the energy in the nuclei of atoms, which can be released by fission or fusion of the nuclei. Power stations using nuclear energy are not within the scope of IPPC and nuclear energy is not dealt with in this document. However, electricity generated by nuclear power forms part of the energy mix of Europe, see Annex 11.

6. **Elastic energy** is the energy stored in elastic intermolecular bonds. In industry it is most often released as a result of pressure changes in gases and steam (where the energy stored in charged atoms compressed together is released as they move apart).

7. **Gravitational energy** is the work done by gravity. While this can be seen in industry, e.g. in the moving of materials down chutes, its role in energy efficiency is limited to some energy calculations. Lifting and pumping, etc. are carried out by machines using electrical energy.

### Potential and kinetic energy

All of the energies listed above are potential energies, where the energy is stored in some way, e.g. in the chemical bonds of a stable substance, in radioactive material etc. Gravitational potential energy is that energy stored due to the position of an objective relative to other objects, e.g. water stored behind a dam. Kinetic energy is energy due to the movement of a body or particles. The classical example is a pendulum, where the maximum potential energy is stored in the pendulum at the top of its arc, and the maximum kinetic energy is when it is moving at the base of the arc. As can be seen from this basic example, the energies change from one form to another. Most of the fundamental interactions of nature can be linked to some kind of potential energy, although some energies cannot be easily classified on this basis, such as light.

### Heat, heat transfer and work

**Heat (Q)** can be defined as energy in transit from one mass to another because of a temperature difference between the two. It accounts for the amount of energy transferred to a closed system during a process by means other than work. The transfer of energy occurs only in the direction of decreasing temperature. Heat can be transferred in three different ways:

- **conduction** is the transfer of energy from the more energetic particles of a substance to the adjacent particles that are less energetic due to interactions between the particles. Conduction can take place in solids, liquids and gases
- **convection** is the energy transfer between a solid surface at a certain temperature and an adjacent moving gas or liquid at another temperature
- **thermal radiation** is emitted by matter as a result of changes in the electronic configurations of the atoms or molecules within it. The energy is transported by electromagnetic waves and it requires no intervening medium to propagate and can even take place in vacuum.

In thermodynamics, **work (W)** is defined as the quantity of energy transferred from one system to another. Mechanical work (motive power) is the amount of energy transferred by a force. Work can also be expressed as the useful effect a system is capable of producing, such as raising a weight to a certain height.

### Power and energy

The terms ‘energy’ and ‘power’ are frequently used interchangeably. However, in physics, and electrical engineering, ‘electrical energy’ and ‘electric power’ have different meanings. Power is energy per unit time (the rate of energy transfer by work). The SI unit of power and electricity is the watt. One watt is one joule per second. The phrases ‘flow of power’ and ‘to consume a quantity of electric power’ are both incorrect and should be ‘flow of energy’ and ‘to consume a quantity of electrical energy’. Units commonly used when discussing industrial energy efficiency are kilowatt (kW) and megawatt (MW) (and kWh or MWh for power).[3]

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[3] The usual unit used to measure electrical energy is a watt-hour, which is the amount of energy drawn by a one watt load (e.g. a tiny light bulb) in one hour. The kilowatt-hour (kWh), which is 1,000 times larger than a watt-hour (equates to single element electric fire), is a useful size for measuring the energy use of households and small businesses and also for the production of energy by small power plants. A typical house uses several hundred kilowatt-hours per month. The megawatt-hour (MWh), which is 1,000 times larger than the kilowatt-hour, is used for measuring the energy output of large power plants, or the energy consumption of large installations.

## 1.2.2 Laws of thermodynamics

As can be seen from Section 1.2.1, one form of energy can be transformed into another with the help of a machine or device, and the machine can be made to do work. Thermodynamics is the study of energy and its transformations and there are key concepts, or laws, of thermodynamics. Some knowledge of the first two of these is essential in understanding energy and energy efficiency.[4]

The relationships and concepts of these various energies are defined mathematically according to whether they are 'closed' or 'open' systems (e.g. if energy – usually heat – or chemicals are lost to the surroundings or kept within the 'system', where 'system' here means the system being studied, see Figure 1.2. In reality, industrial systems are 'open'). The properties of the system must also be defined, such as temperature, pressure and concentration of chemical components, and the changes and rates of change of any of these.

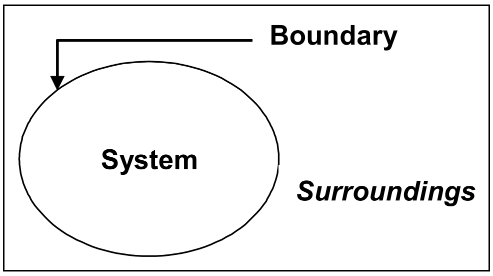

**Figure 1.3: Thermodynamic system**

### 1.2.2.1 The first law of thermodynamics: the conversion of energy

This law states that *energy can neither be created nor destroyed.* It can only be transformed. This means that the total flow of energy into a defined system must equal the total flow outwards from the system.

Unfortunately, the terms, '*energy production'* or *'energy generation'* (although technically incorrect) are widely used, and appear in this document (as the term *'energy transformation'* is not widely used in industrial applications and appear unusual to some readers). The term *'energy use'* is widely used, as it implies neither creation nor destruction of energy. These terms are generally taken to mean the transformation of one form of energy into other forms of energy or work.

- For a closed system, the first law implies that the change in system energy equals the net energy transfer to the system by means of heat and work. That is:

$$U_2 - U_1 = Q - W \qquad \text{(In SI units, this is in joules)}$$

Where:
$U_1$ = the internal energy before change
$U_2$ = the internal energy after change
$Q$ = heat
$W$ = work

---

[4] These laws can be summarised as: (1) The first Law says you can't win, the best you can do is break even. (2) The second Law says you can only break even at absolute zero. (3) The third Law says you can never reach absolute zero [W.J. Moore, Physical Chemistry, 5th edition, 1974].

The Theory of Relativity combines energy and mass, therefore, both energy and matter are conserved, and the flows of energy and matter in and out a defined system must balance. As mass is only changed into energy in nuclear fusion and fission reactions, this enables energy (and mass) balances to be calculated for reactions and processes. This is the basis of energy audits and balances, see Sections 2.7.4.

Energy efficiency according to the first law (thermal efficiency) is given as:

$$\eta = \frac{W_{net,out}}{Q_{in}}$$ [2, Valero-Capilla, 2005]

Where:
η = efficiency
W = work
Q = heat

It can also be described as:

$$\text{efficiency } \eta = \frac{\text{power output}}{\text{power input}} = \frac{\text{work (W)}}{\text{energy (E)}}$$

Where: E = energy

In SI units, both useful work done by the process and the energy (E) are in joules, so the sum is dimensionless, between 0 and 1, or as a percentage.

#### 1.2.2.2 The second law of thermodynamics: entropy (or disorder) increases

The second law states that *the entropy (see below) of a thermodynamically isolated system tends to increase over time.*

The ***entropy*** is[5]:

$$\underbrace{S_2 - S_1}_{\substack{Entropy\\change}} = \underbrace{\int_1^2 \left(\frac{\delta Q}{T}\right)}_{\substack{Entropy\\transfer\\rev.process}}$$ [2, Valero-Capilla, 2005](In SI units = J/K)

Where:
S = entropy
Q = heat
T = temperature

---

[5] For a closed system and a reversible process, as Q is not defined for an open system.

This law describes the quality of a particular amount of energy, and the direction of the universe and all processes. The mathematical term *entropy* can be explained in different ways, which may help the understanding of this concept:

- energy that is dispersed, 'useless' energy, or broken down into 'irretrievable heat' (dispersed into molecular movements or vibrations)
- a measure of the partial loss of the ability of a system to perform work due to the effects of irreversibility
- quantifies the amount of disorder (randomness) between the initial and final states of a system (e.g. the ways the molecules are arranged): i.e. this increases with time. As a consequence, pressure and chemical concentration also flow from the systems of higher pressure or concentration to lower ones, until the systems are at equilibrium.

There are various consequences of this law, some of which may also help to explain this concept[6]:

- in any process or activity, there is an inherent tendency towards the loss (or dissipation) of useful energy or work
- heat moves in predictable ways, e.g. flowing from a warmer object to a cooler one
- it is impossible to transfer heat from a cold to a hot system without at the same time converting a certain amount of energy to heat
- work can be totally converted into heat, but not vice versa
- it is impossible for a device working in a cycle to receive heat from a single reservoir (isolated source) and produce a net amount of work: it can only get useful work out of the heat if the heat is at the same time transferred from a hot to a cold reservoir (it is not possible to get something out of a system for nothing). This means that a perpetual motion machine cannot exist.

In practical terms, it means no energy transformation can be 100 % efficient (note the explanation of lower heat value, below, Section 1.3.5.2). However, it does mean that a reduction in the increase of entropy in a specified process, such as a chemical reaction, means that it is energetically more efficient.

A system's energy can therefore be seen as the sum of the 'useful' energy and the 'useless' energy.

The ***enthalpy*** (H) is the useful heat (heat energy) content of a system and is related to the internal energy (U), pressure (P) and volume (V):

$$H = U + PV$$ [2, Valero-Capilla, 2005] (In SI units, this is in joules)

(U is associated with microscopic forms of energy in atoms and molecules)

As a system changes from one state to another, the enthalpy change ΔH is equal to the enthalpy of the products minus the enthalpy of the reactants:

$$\Delta H = H_{final} - H_{initial}$$ (In SI units, this is in joules)

The final ΔH will be negative if heat is given out (exothermic), and positive if heat is taken in from its surroundings (endothermic). For a reaction in which a compound is formed from its composite elements, the enthalpy change is called the **heat of formation** (or **specific enthalpy change**) of the compound. There are specific enthalpy changes for combustion, hydrogenation, formation, etc.

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[6] There are other corollaries of this law, such as the universe is relentlessly becoming more disordered with time.

Physical changes of state, or phase, of matter are also accompanied by enthalpy changes, **called latent heats** or **heats of transformation**. The change associated with the solid-liquid transition is called the heat of fusion and the change associated with the liquid-gas transition is called the heat of vaporisation.

A system's energy change can therefore be seen as the sum of the 'useful' energy and the 'useless' energy. To obtain work, the interaction of two systems is necessary. **Exergy *(B)*** is the maximum useful work obtained if the system is brought into equilibrium with the environment (the same T, P, chemical composition, see Section 1.2.2.4).

The ratio of exergy to energy in a substance can be considered a measure of energy quality. Forms of energy such as kinetic energy, electrical energy and **Gibbs free energy** (G) are 100 % recoverable as work, and therefore have an exergy equal to their energy. However, forms of energy such as radiation and thermal energy cannot be converted completely to work, and have an exergy content less than their energy content. The exact proportion of exergy in a substance depends on the amount of entropy relative to the surrounding environment as determined by the second law of thermodynamics.

Exergy needs the system parameters to be defined (T, P, chemical composition, entropy, enthalpy) and can be expressed according to which parameters are being held constant. For example, in a system with a given concentration of chemicals at given temperature and pressure, the exergy equals the Gibbs free energy, G:

$$\text{Exergy (B)} = G = \text{enthalpy} + \text{entropy}; \quad G = H + S$$

For chemical processes, the change in G at temperature T is more important:

$$\Delta G = \Delta H + T\Delta S$$

As a practical illustration of 'useful energy': 300 kg of steam at 400°C at 40 bar and 6 tonnes of water at 40°C contains the same amount of energy (assuming the same reference temperature), i.e. 1 GJ. The steam at 40 bar can achieve useful work (via equipment), such as generating electricity, moving mechanical equipment, heating, etc. but there is limited use for water at 40°C. The exergy of the low temperature stream can be raised but this requires the expenditure of energy. For example, heat pumps can be used to increase exergy, but consume energy as work.

### 1.2.2.3 Exergy balance: combination of first and second laws

The first and second laws can be combined into a form that is useful for conducting analyses of exergy, work potential and second law efficiencies among others. This form also provides additional insight into systems, their operation and optimisation. see Section 2.10.

**Exergy balance for an open system**
The exergy rate balance at constant volume is equal to: [2, Valero-Capilla, 2005]

$$\underbrace{\frac{dE_{cv}}{dt}}_{\substack{\text{Rate}\\\text{of}\\\text{exergy}\\\text{change}}} = \underbrace{\sum_j \left(1 - \frac{T_0}{T_j}\right)\dot{Q}_j - \left(\dot{W}_{cv} - P_0 \frac{dVcv}{dt}\right) + \sum_i \dot{m}_i\, e_i - \sum_e \dot{m}_e\, e_e}_{\substack{\text{Rate}\\\text{of}\\\text{exergy}\\\text{transfer}}} - \underbrace{\dot{I}}_{\substack{\text{Rate}\\\text{of}\\\text{Exergy}\\\text{destruction}}}$$

Where: $E_{cv}$ = Exergy at constant volume
T = temperature
t = time
The terms $m_ie_i$ and $m_es_e$ = the rates of exergy transfer into and out of the system accompanying mass flow m ($m_i$ to $m_e$)
$Q_j$ = the time rate of heat transfer at the location on the boundary where the instantaneous temperature is $T_j$
I = rate of exergy destruction
P = pressure
V = volume
$W_{cv}$ = work at constant volume

For a steady flow system, the balance obtained is:

$$0 = \sum_j \left(1 - \frac{T_0}{T_j}\right)\dot{Q}_j - \dot{W}_{cv} + \sum_i \dot{m}_i e_i - \sum_e \dot{m}_e e_e - \dot{I}$$

**Industrial applications**
Application of exergy to unit operations in chemical plants was partially responsible for the huge growth of the chemical industry during the twentieth century. During this time it was usually called available work.

One goal of energy and exergy methods in engineering is to compute balances between inputs and outputs in several possible designs before a unit or process is built. After the balances are completed, the engineer will often want to select the most efficient process. However, this is not straightforward:

- an energy efficiency or first law efficiency will determine the most efficient process based on losing as little energy as possible relative to energy inputs
- an exergy efficiency or second law efficiency will determine the most efficient process based on losing and destroying as little available work as possible from a given input of available work.

A higher exergy efficiency involves building a more expensive plant, and a balance between capital investment and operating efficiency must be determined.

#### 1.2.2.4 Property diagrams

If the properties of a system are measured (e.g. temperature T, pressure P, concentration, etc) and the system shows no further tendency to change its properties with time, the system can be said to have reached a **state of equilibrium**. The condition of a system in equilibrium can be reproduced in other (similar) systems and can be defined by a set of properties, which are the **functions of state** : this principle is therefore known as the **state postulate**. This implies that the state of a system of one pure substance can be represented in a diagram with two independent properties. The five basic properties of a substance that are usually shown on property diagrams are: pressure (P), temperature (T), specific volume (V), specific enthalpy (H), specific entropy (S). Quality (X) is shown if a mixture of two (or more) substances is involved. The most commonly encountered property diagrams: pressure-temperature (P-T), pressure-specific volume (P-V), temperature-specific volume (T-V), temperature-entropy (T-S); enthalpy-entropy (H-S); and temperature-enthalpy plots (T-H), which are used in Pinch technology (see Section 2.9): These diagrams are very useful in plotting processes. Additionally, the first three diagrams are helpful for explaining the relationships between the three phases of matter.

### Pressure-Temperature (phase) diagram

Phase diagrams show the equilibrium conditions between phases that are thermodynamically distinct.

The p-T diagram (Figure 1.3) for a pure substance shows areas representing single-phase regions, where the phase of the substance is fixed by both the temperature and pressure conditions.

The lines (called *phase boundaries*) represent the regions (or conditions, in this case T and P) where two phases exist in equilibrium. In these areas, pressure and temperature are not independent and only one intensive property (T or P) is required to fix the state of the substance. The sublimation line separates the solid and vapour regions, the vaporisation line separates the liquid and vapour regions and the melting or fusion line separates the solid and liquid regions.

All three lines meet at the triple point, where all the phases coexist simultaneously in equilibrium. In this case, there are no independent intensive properties: there is only one pressure and one temperature for a substance at its triple state.

The critical point is found at the end of the vaporisation line. At pressures and temperatures above the critical point, the substance is said to be at a supercritical state, where no clear distinction can be made between liquid and vapour phases. This reflects that, at extremely high temperatures and pressures, the liquid and gaseous phases become indistinguishable. For water, this is about 647 K (374°C) and 22.064 MPa. At this point, a substance on the left of the vaporisation line is said to be at the state of a sub-cooled or compressed liquid; on the right of the same line, the substance is in a superheated-vapour state.

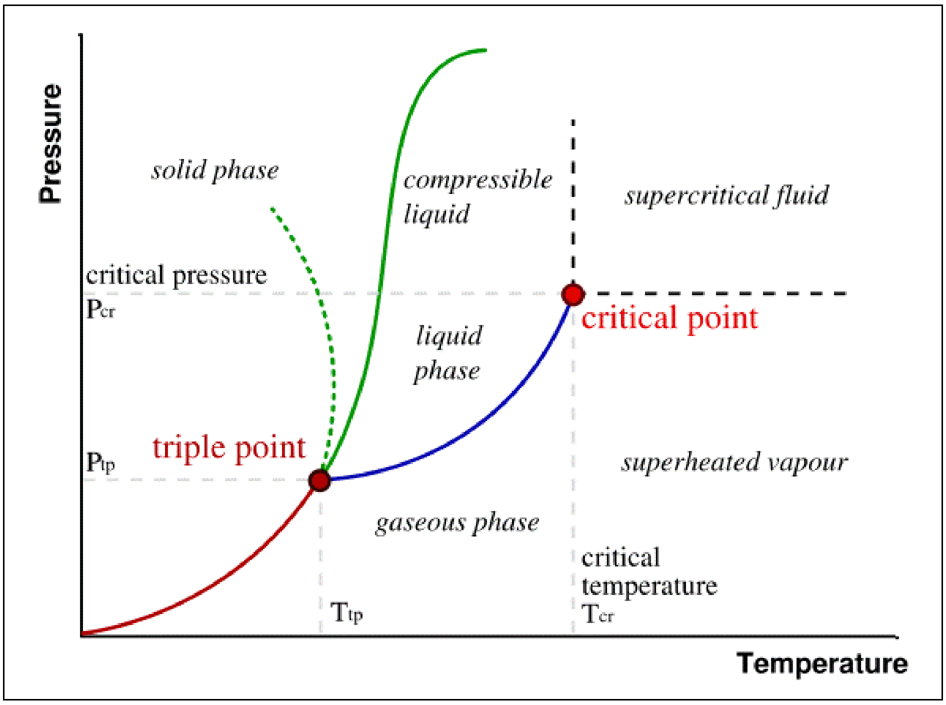

**Figure 1.4: Pressure – Temperature (Phase) diagram needs formatting, smaller [153, Wikipedia]**

### 1.2.2.5 Further information

Further information can be found in standard text books on thermodynamics, physical chemistry, etc.

A wide range of literature and databases provide information on tables of values of the thermodynamic properties of various substances and diagrams of their inter-relationships. These are derived from experimental data. The most frequently listed properties in tables are: specific volume, internal energy, specific enthalpy, specific entropy and specific heat. Property tables can be found in thermodynamic books, on the internet, etc.

As two intensive properties must be known to fix the state in one-phase regions, the properties V, U, H and S are listed versus temperature at selected pressures for superheated vapour and compressed liquid. If there are no available data for a compressed liquid, a reasonable approximation is to treat compressed liquid as saturated liquid at the given temperature. This is because the compressed liquid properties depend on temperature more strongly than they do on pressure.

The so-called 'saturation' tables are used for saturated liquid and saturated vapour states. Since in two-phase regions, pressure and temperature are not independent, one of the properties is enough to fix the state. Therefore, in saturation tables, the properties V, U, H and S for saturated liquid and saturated vapour are listed either versus temperature or pressure.

Some major data compilations can be found from the following sources:

- the American Petroleum Institute, API
- Beilstein Institute of Organic Chemistry, Beilstein
- Design Institute for Physical Property Data, DIPPR of AIChE (DIPPR has a comprehensive pure component data compilation)
- Deutsche Gesellshaft für Chemisches Apparatewesen, Chemische Technik und Biotechnologie e.V., DECHEMA (a primary source of mixture data)
- Physical Property Data Service, PPDS in the UK.

Commercial simulation programs with extensive capabilities for calculating thermodynamic properties can be easily found. Three well-established programs are trademarked: ASPEN PLUS, HYSIM, and PRO/II. However, these programs may be more powerful than required for energy saving analysis, or may not be suitable for this task. These programs are costly in acquisition, in effort of use and maintenance. Intermediate solutions that allow the analyst to simulate their own solutions and include pure substance properties are, for instance, EES, Thermoptim, and BBlocks. Selecting and using such programs therefore requires time and expertise.

### 1.2.2.6 Identification of irreversibilities

In thermodynamics, a *reversible process* is theoretical (to derive concepts) and in practice all real systems are *irreversible*. This means they cannot be reversed spontaneously; but only by the application of energy (a consequence of the Second Law). The mechanical, thermal and chemical equilibrium conditions of a thermodynamic system also imply three causes of disequilibrium or irreversibilities (these may be seen as thermodynamic inefficiencies in practice). Changes are caused by driving forces (temperature; pressure, concentration, etc. as dictated by the second law of thermodynamics). In theory, the smallest possible driving forces should be applied to achieve a net result. However, in practical processes, driving forces cannot be completely avoided. The smaller the driving forces, the larger the required equipment size gets, e.g. a low pressure process requires a larger plant size for the same throughput as a high pressure process, which is more space and capital efficient.

**Mechanical irreversibilities** are due to pressure changes and also always appear in processes that involve friction. Entropy increases and exergy decreases are always associated with mechanical irreversibilities; the greater the pressure change, the greater the irreversibility created within the system.

**Thermal irreversibilities** appear when there is a finite temperature change within the system as, for instance, in every heat exchanger. The heat passes from a warm body to a cold one spontaneously, thereby losing exergy. Again, the larger the temperature change, the larger the loss of exergy and the more irreversible the process.

**Chemical irreversibilities** are due to a chemical disequilibrium, occurring in mixtures, solutions and chemical reactions. For example when water and salt are mixed, exergy of the system is decreased. This exergy loss is equivalent to the minimum work that has been previously needed to purify water in order to obtain the salt, e.g. by distillation, ion exchange or membrane filtration, drying, etc.

The thermodynamic analysis of irreversible processes reveals that in order to obtain a good efficiency and save energy, it is necessary to control and minimise all the mechanical, thermal and chemical irreversibilities appearing in the plant.

Examples of each of these irreversibilities are given in Annex 2.

#### 1.2.2.7 Energy transfer

The forms of energy discussed in this section (Section 1.2.1) which constitute the total energy of a system are static forms of energy and can be stored in a system. However, energy can also be transformed from one form to another and transferred between systems. For closed systems, energy can be transferred through work and heat transfer. Heat and work are not properties because they depend on the details of a process and not just the initial and final states.

#### 1.2.2.8 Energy inefficiencies

Inefficiencies in the transformation of energy into work and other forms of energy occur from one or a combination of:

- thermodynamic irreversibilities (see Section 1.2.2.6)
- poor efficiency in transferring energy by conduction, convection or radiation (see Section 1.2.1, introduction)
- the inefficient or unnecessary transformation (use) of energy in any form e.g. poor design , operation and maintenance, running equipment when not needed, such as lighting, or running processes at a higher temperature than necessary, etc).

## 1.3 Definitions of and indicators for energy efficiency and energy efficiency improvement

[4, Cefic, 2005], [5, Hardell and Fors, 2005] [62, UK_House_of_Lords, 2005, 63, UK_House_of_Lords, 2005, 92, Motiva Oy, 2005].

### 1.3.1 Energy efficiency and its measurement in the IPPC Directive

[4, Cefic, 2005, 92, Motiva Oy, 2005]

'Energy efficiency' is a term that is widely used qualitatively as the means to address different objectives, such as policy at national and international level, as well as business objects, principally (as can be seen in the Preface)[7]:

- reduction of carbon emissions (climate protection)
- enhancement of the security of energy supplies (through sustainable production)
- reduction of costs (improvement in the competitiveness of business).

Initially 'energy efficiency' appears to be simple to understand. However, it is not usually defined where it is used, so *'energy efficiency can mean different things at different times and in different places or circumstances'*. This lack of clarity has been described as *'elusive and variable'*, leading to *'inconsistency and muddle'* and where energy savings need to be presented in quantitative terms, the lack of adequate definitions is *'embarrassing, especially when comparisons are made between major industries or between industry sectors'*. There is no definition of ‘energy efficiency’ in the IPPC Directive, and this section discusses the issues relating to its definition in the context of an installation and permit. [62, UK_House_of_Lords, 2005, 63, UK_House_of_Lords, 2005].

As the IPPC Directive deals with production processes within an installation, the focus of this document is the physical energy efficiency at an installation level. The life cycles of products or raw materials are therefore not considered (this is addressed in products policy, see Scope).

Economic efficiency is also discussed, where there are data and/or it is relevant (such as in individual techniques, and see Section 1.5.1). Thermodynamic efficiencies are discussed above, and as relevant in individual techniques, see Section 1.3.

Energy efficiency may be reduced by measures to improve the environmental impacts of products or by-products, etc (see Section 1.5.2.5). This is outside of the scope of this document.

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[7] The other major energy efficiency policy is the reduction of fuel poverty (e.g. households that cannot afford to keep warm in winter). This is a societal issue, and is not directly related to industrial energy efficiency and IPPC.

### 1.3.2 Energy efficiency indicators

Energy efficiency is defined in the EuP Directive [148, EC, 2005] as:

> *a ratio between an output of performance, service, goods or energy, and an input of energy.*

This is the amount of energy consumed per unit of product/output, and is referred to as the specific energy consumption (SEC), and is the definition most commonly used by industry. (Note: the definition below is widely used in the petrochemical and chemical industries, but is called the 'energy intensity factor', EIF, see below)

In its simplest form, the SEC can be defined as: **Eq 1**

$$\text{SEC} = \frac{\text{energy used}}{\text{products produced}} = \frac{(\text{energy imported} - \text{energy exported})}{\text{products/outputs produced}}$$

SEC is a number with dimensions, e.g. GJ/tonne. Note: the energy exported may be greater than the energy imported, where the installation produces energy, e.g. power generation, waste incineration, etc.

The term 'energy intensity factor' (EIF) is also used (see note above, on its use in petrochemical industries). This is usually understood by economists as the ratio of the energy used to a financial value, such as business turnover, value added, etc e.g.:

**Eq 2**

$$\text{EIF} = \frac{\text{energy used}}{\text{turnover of installation}} = \text{GJ/ EUR turnover}$$

However, as the price of outputs usually rises over time, the EIF can decrease without any increase in physical energy efficiency. The term should therefore be avoided in assessing the physical energy efficiency of an installation.

It is also used at the macro level (e.g. European and national) and is then expressed as, e.g. GJ per unit of GDP (gross domestic product), which can then be used to measure the energy efficiency of a nation's economy.

The units used therefore need to be clarified, especially when comparing industries or sectors. [158, Szabo, 2007]

It is important to note the difference between primary energies (such as fossil fuels) and secondary energies (such as electricity, steam, see Section 1.3.5.1, below). All secondary energy should be converted to the primary energy content, and this term then becomes the specific consumption of primary energy. It can be expressed as, e.g. primary energy per tonne of product in MJ/tonne or GJ/tonne [91, CEFIC, 2005].

### Denominator in specific energy consumption and energy efficiency index

In the simplest case, the production unit will produce one main product, which can then be used as the divisor in the SEC formula. In many cases the situation may be more complex, such as where there may be multiple products in refineries or large chemical plants, where the product mix varies with time, or where there is no obvious product e.g. in waste management facilities. In such cases, as discussed in Section 1.4, below, other production criteria can be used, such as where:

1. there are a number of equally important products or a number of important co-products. Where appropriate, the sum of these products can be used as the divisor. Otherwise, meaningful process boundaries have to be decided between the energy balance and the products balance

$$SEC = \frac{\text{energy used}}{\sum \text{products produced}} = \frac{(\text{energy imported} - \text{energy exported})}{\sum \text{products produced}}$$

2. there are several product streams and the number of raw materials (feedstock) streams are low, the denominator may be the raw material. An example is mineral oil refineries, with typically 5 to 7 output streams and one input stream. This is recommended if the energy consumption is determined mainly by the amount of raw material and less by the products (which may happen when the product quality depends on the feedstock). However, using raw material as a denominator does not reflect the loss of (decrease in) energy efficiency when raw material and energy consumption remain the same but production quantities decrease

$$SEC = \frac{\text{energy used}}{\sum \text{raw material input}} = \frac{(\text{energy imported} - \text{energy exported})}{\sum \text{raw material input}}$$

3. there are several products (or one product with different specifications) produced in batches or campaigns. An example is a polymer plant producing different grades of polymer, each one manufactured in turn, and for differing periods, according to market needs. Each grade will have its own energy consumption, usually higher quality grades require more energy input. It may be useful to define a reference energy efficiency for each grade (based on the average energy consumption for that given grade). The relevant energy efficiency indicator over a specific period could then be defined:

$$EEI = \frac{\sum_{i-A,B,C} Xi * SEC_{refi\_}}{\dfrac{\textit{Energy used in production unit over period considered}}{\textit{Sum of products of A, B, and C produced during period}}}$$

Where: xi is the fraction of grade i on total product produced over the given period
$SEC_{ref,i}$ is the reference energy efficiency factor for grade i (calculated, for instance, by averaging the energy efficiency indicator over a reference period when only grade i was produced).

4. there is no obvious product e.g. in waste management facilities. In this case, the production criteria related to the energy used is the waste input

5. other cases where the energy-to-end-product ratio (or main throughout) is too variable to be useful. Examples are printing installations, where the amount of printed paper input/output does not always relate to the energy use. This is because the amount of printing and drying varies with the amount of ink coverage and the processes used. See the STS BREF.

### Defining improvement in energy efficiency

The EuP Directive [147, EC, 2006] defines energy efficiency improvement as an increase in energy end-use efficiency as a result of technological, behavioural and/or economic changes. The types of change that meet these criteria are discussed in Section 1.5 and generic techniques are described in Chapters 2 and 3.

The efficiency improvement can therefore be expressed as:

- obtaining an unchanged output value at a reduced energy consumption level, or
- obtaining an increased output value with unchanged energy consumption, or
- obtaining an output value that in relative terms surpasses the increase in energy consumption.

[Swedish Energy Agency]

The main purpose of the energy efficiency indicators is to be able to monitor the progress of the energy efficiency of a given production unit and a given production rate over time and to see the impact of energy efficiency improvement measures and projects on the energy performance of the production process/unit. The SEC shows how much energy is used for a given output but one single value is of limited use without other reference data. The energy efficiency index (EEI) can be used to show the change in the given time period and is more useful in monitoring the energy efficiency of a system, process or installation. This is defined by dividing a reference SEC ($SEC_{ref}$) by the SEC of the unit or process being considered. $SEC_{ref}$ can either be a reference number which is generally accepted by the industry sector to which the production process belongs, or it can be the SEC of the production process at a given reference year:

**Eq 3**

$$EEI = \frac{SEC_{ref}}{SEC}$$

The energy efficiency index is a dimensionless number.

Note: SEC is a number that decreases with increasing energy efficiency whereas EEI is a number that increases. Energy management therefore targets the lowest possible SEC and the highest possible EEI.

### Timeframe

An appropriate timeframe should be selected (see Section 2.12 and the Monitoring BREF). If taken on an hourly basis, the energy efficiency indicator may show large fluctuations for a continuous process and would not be appropriate for a batch process. These fluctuations are smoothed out on longer period basis, such as a year or month. However, it should be noted that the variations in a smaller timeframe should be accounted for, as they may identify opportunities for energy saving.

In addition to the two main indicators dealt with here, there are also other indicators and sub-indicators, see Sections 2.7. and 2.12.

### 1.3.3 Introduction to the use of indicators

In industry, the specific energy consumption (SEC) for a given output (or input) is the most widely used indicator, and will be used widely in this document. The definition looks deceptively simple. However, experience in trying to quantify the concept for monitoring processes shows that a framework is required to better define and measure energy efficiency. There are several complicating factors, such as:

- energy is not always counted in the same way or using the same parameters by different operators or staff
- it is often necessary to look at the energy efficiency of a production process within the energy efficiency of a production site involving several production processes
- the definition does not provide information on whether energy is used or produced efficiently.

To be informative and useful, energy efficiency must be comparable, e.g. to another unit or installation, over time and for comparison there must be rules or conventions. In the case of comparing energy efficiency, it is especially important to define system boundaries to ensure all users are considered equally.

At its simplest, the definition neither takes a view on how efficiently energy is produced nor how ‘waste’ energy is used outside the system boundary. These and other issues should be transparent so that it is possible to evaluate improvements in energy efficiency. These issues are discussed in Sections 1.4 and 1.5.

For IPPC, energy efficiency is considered either from the perspective of:

- an installation, or grouping of several production processes/units and/or systems
- an industrial sector or activity in setting values associated with BAT, e.g. in a BREF.

The specific energy consumption and energy efficiency index (above) are examples of energy efficiency indicators. The suitability of different energy efficiency methods and indicators needs to be considered on a sector and process basis, and may need to be considered on a site-by-site basis (see discussion in Benchmarking, Section 2.12). All industrial installations have their individual characteristics. There are differences between raw materials, process technologies, quality of products, mix of products, monitoring methods, etc. The age of the unit can also have a great effect on energy efficiency: new installations usually have better energy efficiency than the old ones [156, Beerkens, 2004, 157, Beerkens R.G.C. , 2006]. Taking into account the range of variables effecting the energy efficiency, comparison between different installations by energy efficiency indicators can lead to wrong conclusions, especially when it is difficult (or even impossible) in practice to take into account all the variables in an appropriate manner [127, TWG].

To evaluate energy efficiency it may be helpful to[CEFIC, 325]:

- assess the site to establish if a specific energy indicator (SEI) can be established for the whole site
- if a site SEI cannot be established, or it is helpful in the energy efficiency analysis, split the site in production/utility units
- define indicators for each production process and for the site or part of it
- quantify specific energy indicators, record how these are defined, and maintain these, noting any changes over time (such as in products, equipment).

## 1.3.4 The importance of systems and system boundaries

The best energy efficiency for a site is not always equal to the sum of the optimum energy efficiency of the component parts, where they are all optimised separately. There are synergies to be gained from considering (in the following order):

1. The whole site, and how the various units and/or systems inter-relate (e.g. compressors and heating). This may include considering the de-optimising of the energy efficiency of one or more production processes/units to achieve the optimum energy efficiency of the whole site. The efficient use of processes, units utilities or associated activities, or even if they are appropriate in their current forms needs to be assessed.
2. Optimising the various units and/or systems (e.g. CAS, cooling system, steam system).
3. Finally, optimising the remaining constituent parts (e.g. electric motors, pumps, valves).

To understand the importance of considering the role of systems in energy efficiency, it is crucial to understand how the definition of a system and its boundary will influence the achievement of energy efficiency. This is discussed in System Boundaries, Section 1.5, and Section 2.2.2.

Furthermore, by extending boundaries outside a company's activities and by integrating industrial energy production and consumption with the needs of the community outside the site, the total energy efficiency could be increased further, e.g. by providing low value energy for heating purposes in the neighbourhood. These issues are beyond an IPPC permit, and are discussed in Chapter 5.

## 1.3.5 Other important related terms

(Other terms used may be found in the Glossary or in standard texts).

### 1.3.5.1 Primary energy and secondary energy

Primary energy is the energy contained in raw fuels and any other forms of energy received by a system as input to the system. The concept is used especially in energy statistics in the course of compilation of energy balances.

Primary energies are transformed in energy conversion processes to more convenient forms of energy, such as electrical energy, steam and cleaner fuels. In energy statistics these subsequent forms of energy forms are called secondary energy (also referred to as derived, final, or designated energy). [Wikipedia]

The use of primary and secondary energies is illustrated in Example 1, Section 1.4.1. When comparing different energy vectors (e.g. steam and/or heat generated in the installation from raw fuels compared against electricity produced externally and supplied via a national grid), it is important to take account of the inefficiencies in the external energy vector(s). If not, as in the example in Section 1.4.1, the external vector can appear significantly more efficient.

Examples of energy vectors that may be supplied from outside the unit or installation are:

**electricity:** the efficiency varies according to fuel and technology, see [125, EIPPCB]. For conventional steam plants, the efficiency of producing electricity from the primary fuel varies between 36 and 46 %. For combined cycle technology, the efficiency is between 55 and 58 %. With combined heat and power (CHP, see Section 3.4.1) a total efficiency for electricity and heat can reach 85 % or more.

**steam**: see Section 3.2.

$$\text{The energetic value of the steam} = \frac{(h_s - h_w)}{\eta_b}$$

where:

| | |
|---|---|
| • $h_s$ | enthalpy of steam |
| • $h_w$ | enthalpy of boiler feed-water (after deaeration) |
| • $\eta_b$ | thermal efficiency of the boiler. |

The whole of the steam system (including the deaerator), and following energy inputs should be included when defining the energy value of steam:

- energy required to pump boiler feed-water to the operating pressure of the boiler
- heat added to boiler feed-water to bring it to the temperature of the deaerator
- steam sparged in the deaerator to remove oxygen from the boiler feed-water
- energy consumed by the air fan providing forced draft to the boiler.

There are other utilities to be considered in a similar way, such as:

- compressed air: see Section 3.7
- hot water
- cooling water: see Section 3.4.3.

Other inputs may not be considered as ‘utilities’ in the conventional sense. However, they may be produced on- or off-site, and/or the use they are put to and the effect on energy usage may be considerable. For example:

- nitrogen: see Section 3.7 on compressed air and the generation of low quality $N_2$
- oxygen: when used in combustion, it may claimed to increase the combustion efficiency. However, if the energy used in producing the oxygen considered, it approximately energy neutral, although it has the significant benefit of reducing $NO_X$.[156, Beerkens, 2004, 157, Beerkens R.G.C. , 2006].

However, calculating energies as primary energy requires time (although this can be readily automated on a spreadsheet for repeat calculations in a defined situation) and is not free of interpretation problems. For example, a new installation equipped with the most energy efficient technologies may be operating in a country whose electricity generation and distribution system are out-of-date. If the low efficiency of the domestic electric production and distribution systems are taken into account, the energy efficiency indicator of the installation compared to similar installations in other countries may be poor. [127, TWG]. Also, the different sources of electricity have different efficiencies of generation, and the mix of generation sources vary according to the country. This problem can be overcome by using standard values, such as the European energy mix, see Annex 11.

From July 1 2004, the [149, EC, 2003] established fuel mix disclosure by the electricity providers. The exact presentation of the data provided are at the discretion of the EU Member States:

http://europa.eu/eur-lex/pri/en/oj/dat/2003/l_176/l_17620030715en00370055.pdf

The European Commission note on implementation can be found at:

http://ec.europa.eu/energy/electricity/legislation/doc/notes_for_implementation_2004/labelling_en.pdf

The Directive on the promotion of cogeneration [146, EC, 2004] and the guidelines related to it, explain reference values of electricity and steam production, including correction factors depending on the geographical location. The Directive also explains the methodology for determining the efficiency of the cogeneration process.

There are various other sources of data, such as national fuel mixes:
http://www.dti.gov.uk/energy/policy-strategy/consumer-policy/fuel-mix/page21629.html

An alternative to returning all energies to primary energy is to calculate the SEC as the key energy vectors, e.g. p338 [220, EIPPCB], the total demand for energy (consumption) in the form of heat (steam) and electric power for a non-integrated fine paper mill was reported [SEPA-report 4712-4, 1997] to consume:

- process heat: 8 GJ/t (≈ 2222 kWh/t)
- electric power: 674 kWh/t.

This means that about 3 MWh electricity and steam/tonne product is consumed. When considering the primary energy demand for converting fossil fuels into power a total amount of 4 MWh/t of paper is needed. This assumed a primary energy yield of the electricity generator of 36.75 %. In this case an electricity consumption of 674 kWh/t corresponds to 1852 kWh/t primary energy (e.g. coal).

In general, primary energy should be used:

- for comparison with other units, systems, sites within sectors, etc.
- when auditing to optimise energy efficiency and comparing different energy vectors to specific units or installations (see Sections 1.4.1 and 1.4.2).

Primary energy calculated on a local (or national) basis can be used for site-specific comparisons, e.g.:

- when seeking to understand local (or national) effects, such as comparing installations in different locations within a sector or a company
- when auditing to optimise energy efficiency and comparing different energy vectors to specific units or installations (see Sections 1.4.1 and 1.4.2). For example, when considering changing from a steam turbine to an electric motor, it would be optimal to use the actual electricity efficiency production factor of the country.

Primary energy calculated on a regional basis (e.g. EU energy mix) for:

- monitoring activities, units, or installations on a regional basis, e.g. industry sector.

Secondary energy can be used:

- for monitoring an ongoing defined situation
- calculated on an energy vector basis, for monitoring site and industry sector efficiencies.

In Section 1.4.1, the final (secondary or designated) energy can be used to compare installations in different countries, and this is the basis for specific energy requirements given in some vertical BREFs (e.g. see PP BREF). Conversely, primary energy could be used to express the overall efficiencies at national level (e.g. to asses the different efficiencies of industry sectors in different countries.

Note that the Commission (in DG-JRC IPTS Energy) and IPCC quote both values in their reports for clarity [158, Szabo, 2007].

### 1.3.5.2 Fuel heating values and efficiency

In Europe, the usable energy content of fuel is typically calculated using the **lower heating value** (LCV, also called the lower combustion value or lower calorific value) of that fuel, i.e. the heat obtained by fuel combustion (oxidation), measured so that the water vapour produced remains gaseous, and is not condensed to liquid water. This is due to the real conditions of a boiler, where water vapour does not cool below its dew point, and the latent heat is not available for making steam.

However, using the LCV, a condensing boiler can achieve a 'heating efficiency' greater than 100 % which breaks the first law of thermodynamics.

In the US and elsewhere, **the higher heating value** (HCV, or higher combustion value) is used, which includes the latent heat for condensing the water vapour, and thus, when using HCVs, the thermodynamic maximum of 100 % cannot be exceeded. The $HCV_{dry}$ is the HCV for a fuel containing no water or water vapour, and the $HCV_{wet}$ is where the fuel contains water moisture.

It is important to take this into account when comparing data using heating values from the US and Europe. However, where these values are used in ratios such as EEI, the difference may be in both nominator and denominator and will be cancelled out. (Some typical HCVs and LCVs are given in Table 1.1, and ratio of $LCV_{wet}$ to $HCV_{wet}$ can be seen to vary from 0.968 to 0.767.

| Fuel | Moisture content [ % w.b.] | Hydrogen content [$kg_H/kg_{fuel}$] | $HCV_{dry}$ [MJ/kg] | $HCV_{wet}$ [MJ/kg] | $LCV_{dry}$ [MJ/kg] | $LCV_{wet}$ [MJ/kg] | Ratio of $LCV_{wet}/HCV_{wet}$ [-] |
|---|---|---|---|---|---|---|---|
| **Bituminous coal** | 2 | 4.7 | 29.6 | 29.0 | 28.7 | 28.1 | 0.968 |
| **Natural gas 1 (Uregnoi, RUS)** | 0 | | 54.6 | 54.6 | 49.2 | 49.2 | 0.901 |
| **Natural gas 2 (Kansas, US)** | 0 | | 47.3 | 54.6 | 42.7 | 42.7 | 0.903 |
| **Heavy fuel oil** | 0.3 | 10.1 | 43.1 | 43.0 | 40.9 | 40.8 | 0.949 |
| **Light fuel oil** | 0.01 | 13.7 | 46.0 | 46.0 | 43.0 | 43.0 | 0.935 |
| **Pine bark non-dried** | 60 | 5.9 | 21.3 | 8.5 | 20 | 6.5 | 0.767 |
| **Pine bark dried** | 30 | 5.9 | 21.3 | 14.9 | 20 | 13.3 | 0.890 |
| Natural gas 1: $CH_4$ (97.1vol- %), $C_2H_6$ (0.8 %), $C_3H_8$ (0.2 %), $C_4H_{10}$ (0.1 %), $N_2$ (0.9 %), $CO_2$ (0.1 %)<br>Natural gas 2: $CH_4$ (84.1vol- %), $C_2H_6$ (6.7 %), $C_3H_8$ (0.3 %), $C_4H_{10}$ (0.0 %), $N_2$ (8.3 %), $CO_2$ (0.7 %) | | | | | | | |

**Table 1.1: Low and high heating values for various fuels**
**[153, Wikipedia]**

### 1.3.5.3 Demand side and supply side management

Supply side refers to the supply of energy, its transmission and distribution. The strategy and management of the supply of energy outside of the installation is outside of the scope of the IPPC Directive (although the activity of electricity generation is covered as defined in the Directive Annex 1(1.1)). Note that in an installation where power is generated in a utility or associated process, the supply of this energy to another unit or process within the installation may be also referred to as 'supply side'.

Demand side management means managing the energy demand of a site, and a large amount of the literature relating to energy efficiency techniques refers to this issue. However, it is important to note that this has two components: the cost of the energy per unit and the amount of energy units used. It is important to identify the difference between improving the energy efficiency in economic terms and in physical energy terms (this is explained in more detail in Chapter 5).

# 1.4 Energy efficiency indicators in industry

## 1.4.1 Introduction: defining indicators and conventions

The main aim of indicators is to assist self-analysis and monitoring, and to assist in comparing energy efficiency of units, activities or installations. While Eq.1 and 3 appear simple, there are related issues which must be defined and decided before using the indicators, especially when comparing one production process with another. For example, process perimeters, system boundaries, energy vectors and how to compare different fuels and fuel sources (and whether they are internal or external sources). Once these factors have been defined for a specific plant or for an inter-site benchmark, they must be adhered to.

This section discusses how to define energy efficiency and indicators for individual industrial production processes/units/sites. It explains what the relevant issues are and how to consider them in order to measure and evaluate the changes in energy efficiency.

There are problems ensuring that the data from separate units or sites are truly comparable, and if so, whether conclusions may be drawn about the economics of a site, that affect confidentiality and competition. These issues and the use of these indicators is discussed in Section 2.12, Benchmarking.

## 1.4.2 Energy efficiency in production units

The following two examples illustrate the concepts of SEC and EEI, and highlight key interpretation issues.

### 1.4.2.1 Example 1. Simple case

Figure 2.1 shows an example of a simple production unit[8]. For simplicity, the process is shown without energy exports and with only one feedstock and one product. The production process makes use of steam, electricity and fuel.

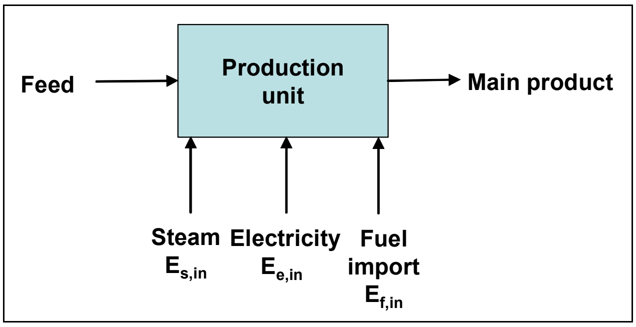


**Figure 1.5: Energy vectors in a simple production unit**

The SEC of this process is given by:

**Eq 4**

$$\text{SEC} = \frac{E_{s,in} + E_{e,in} + E_{f,in}}{P}$$

Where:

$E_{s,in}$ = energy supplied to the process via steam to produce an amount of product P
$E_{e,in}$ = energy supplied to the process via electricity to produce an amount of product P
$E_{f,in}$ = energy supplied to the process via fuel to produce an amount of product P

In Eq. 2.3, it is essential that the various energy vectors (energy flows) are expressed as **primary energy** and on the same basis (see Section 1.3.5.1). For instance, 1 MWh of electricity requires more energy to be produced than 1 MWh of steam, as electricity is typically generated with an efficiency of 35 – 58 % and steam with an efficiency of 85 – 95 %. The energy use of the different energy vectors in the equation above therefore needs to be expressed in primary energy. This includes the efficiency to produce that energy vector.

An example of a calculation of energy efficiency
Assume that to produce 1 tonne of product P1, the following energy vectors have to be used:

- 0.01 tonne of fuel
- 10 kWh of electricity
- tonne of steam.

Assuming the following[8]

- lower calorific value of fuel = 50 GJ/tonne
- efficiency of electricity production = 40 %
- steam is generated from water at 25°C the difference between the enthalpy of steam and the enthalpy of water at 25°C = 2.8 GJ/tonne
- steam is generated with an efficiency of 85 %.

To produce 1 tonne of product P1, the energy consumption is (converting to GJ):

- $E_{f,in}$ = 0.01 tonne fuel x 50 GJ/tonne = 0.50 GJ
- $E_{e,in}$ = 10 kWh x 0.0036 GJ/kWh x 100/40 = 0.09 GJ (where 1 kWh = 0.0036 GJ)
- $E_{s,in}$ = 0.1 tonne steam x 2.8 GJ/tonne x 1/0.85 = 0.33 GJ.

The SEC of this process is then given by:

- SEC = (0.50 + 0.09 + 0.33) GJ/tonne = 0.92 GJ/tonne.

---

[8] The figures are illustrative only, and not intended to be exact. No pressure is given for steam, but it can be assumed to be the same in both parts of the example. An exergy analysis would be more useful, but is beyond this simple example.

To determine the EEI, assume that this is the reference SEC. Now assume that the plant carries out a number of energy efficiency improvement projects, so that a year later the energy consumption of the production process has become:

- tonne of fuel
- 15 kWh of electricity
- 0.05 tonne of steam.

As a result of these energy efficiency improvement projects, the new SEC of the process is:

- SEC = (0.5 + 0.135 + 0.165) GJ/tonne = 0.8.

The EEI of this process is then:

- EEI = 0.92/0.8 = 1.15.

This indicates that the energy efficiency of the production process has increased by 15 %.

It is important to note that the inefficiencies of the production of electricity in this case have been internalised (by using the primary energy: these inefficiencies are actually external to the site). If this is not taken account, the electrical energy input would appear to be 50 % more efficient than it is:

$$\frac{(0.09 - 0.036)}{0.036} = 1.5; \qquad \text{i.e. } 150\ \%$$

Ignoring the primary energy may lead to, for example, decisions to switch other energy inputs to electricity. However, it would need more complex analysis beyond the scope of this example to determine the amount of useful energy available in the application of sources, such as an exergy analysis.

This example shows it is therefore important to know on what basis the SEC and the EEI are calculated.

It is also important to note the same logic applies to other utilities that may be brought into the unit/process/installation from outside the boundary (rather than produced within the boundary), such as steam, compressed air, $N_2$, etc (see primary energy, Section 1.3.5.1).

#### 1.4.2.2 Example 2. Typical case

Figure 2.2 deals with a more realistic case, where there is both export of energy and internal recycling of fuel or energy. This case illustrates principles that are applicable to many industries, with appropriate adjustments.

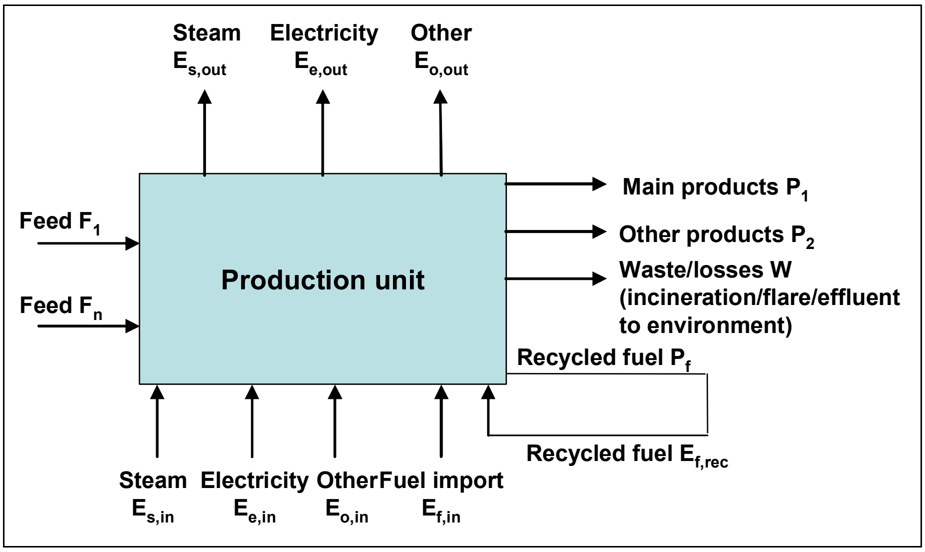


**Figure 1.6: Energy vectors in a production unit**

**Eq 5**

$$SEC = \frac{(E_{s,in} + E_{e,in} + (E_{f,in} + E_{f,rec}) + E_{o,in}) - (E_{s,out} + E_{e,in} + E_{f,in})}{P_1}$$

This generic formula can be applied to each production process/unit/installation, but its various components have to be adapted to each specific production process/unit/site. The unit of this indicator is (unit of energy)/(unit of mass) usually GJ/t product or MWh/t product. However, there are multiple products or one main product and significant by-products.

Some considerations to taken into account when applying Eq. 5 are described in the seven points follow (some are also applicable to Eq. 4):

**1. Feed/product flows ($F_i$, $P_i$)**

In Figure 2.2, the mass-flow of the raw materials and products is shown in the horizontal direction. The feeds $F_i$ are the different raw materials used to produce the main products $P_1$ and the by-products. These by-products are split in two fractions: a fraction which is recycled as fuel ($P_f$) and the remaining by- products ($P_2$).

Examples of this situation are:

- the ethylene steam crackers in the petrochemical industry, where energy consumption can be expressed in GJ per tonne ethylene, in GJ per tonne olefins (ethylene + propylene) or in GJ per tonne of high value chemicals (olefins + butadiene + benzene + pure hydrogen)
- in the chlor-alkali sector where energy consumptions are usually related to the tonnes of $Cl_2$ produced (the main product), and $H_2$ and NaOH are by-products.

### 2. Energy vectors (energy flows) ($E_i$)

The energy vectors show the different types of energy flows into and out of the unit. The energy imported and the energy which is exported for use elsewhere are shown in the vertical plane in Figure 2.2. The following energy vectors are considered:

- $E_S$ = steam and/or hot water
- $E_e$ = electricity to the process
- $E_f$ = fuel (gas, liquid, solid). A split is made between the externally purchased fuel $E_f$ and the fuel which is internally recycled in the process $E_{f,rec}$
- $E_O$ = other: this covers any utility which requires energy to be produced. Examples are hot oil, cooling water, compressed air and $N_2$ (when processed on-site). This cooling water requires energy to produce it (energy is required to operate the pumps circulating cooling water and the fans on the cooling towers).

It is important that, on the output side, only those energy vectors which are beneficially used in a process or unit in another process are counted. In particular, the energy associated with the cooling of the process by cooling water or air should never be included as the ‘energy out’ in Eq. 2.4. The energy used in supplying different utilities and other associated systems must also be considered. For example, for cooling water (operation of pumps and fans), compressed air, $N_2$ production, steam tracing, steam to turbines, etc. Other heat losses to the air should also never be counted as useful energy outputs. The appropriate sections in Chapter 3 on these ancillary systems give more data on their efficiencies and losses.

### 3. Different steam levels ($E_s$) (and hot water levels)

The production plant could be using or producing more than one type of steam (different pressures and/or temperatures). Each level of steam or water may have to produce its own efficiency factor. Each of these steam levels needs to be included in the term $E_s$ by summing up their entropies [127, TWG]. See steam, in Section 3.2.

Hot water, if used (or produced and used by another production plant), should be treated similarly.

### 4. Waste material flows (W)

Each process will also generate an amount of waste products. These waste products can be solids, liquids or gaseous and may be:

- disposed of to landfill (solids only) or by incineration
- used as fuel ($P_f$)
- recycled.

The relevance of this waste stream will be discussed in more detail in Section 1.5.2.3. Waste energy is dealt with as an energy flow.

### 5. Fuel or product or waste ($E_0$, $P_f$)

In Figure 2.2, fuel is not shown as an exported energy vector. The reason for this is that fuel ($P_f$) is considered as a product rather than an energy carrier and that the fuel value, which would be attributed to the fuel, is already accounted for in the feed going to the production unit. This convention is standard within refineries and the chemical industry.

Other industries may apply different practices. For instance, in the chlor-alkali industry, some operators count the $H_2$ (a by-product of the $Cl_2$ and NaOH produced) as an energy vector, independent of whether this $H_2$ is subsequently used as a chemical or as a fuel (the $H_2$ flared is not counted).

It is therefore important to establish the rules for defining energy efficiency specific to a given industrial sector such as feeds, products, energy carriers imported and energy carriers exported**.** See also Waste material flows, Section 1.5.2.3.

### 6. Measured or estimated

Eq. 2.4 assumes that the different energy vectors to the production process are known. However, for a typical production process, some parameters, e.g. the different utility consumptions (e.g. cooling water, nitrogen, steam tracing, steam to a turbine, electricity) are not always measured. Often, only the major individual utility consumptions of the production process are measured in order to control the process (e.g. steam to a reboiler, fuel to a furnace). The total energy consumption is then the sum of many individual contributors, of which some are measured and some are ‘estimated’. Rules for estimation must be defined and documented in a transparent way. See Sections 1.5 and 2.7, Monitoring.

### 1.4.3 Energy efficiency of a site

Complex production sites operate more than one production process/units. To define energy efficiency of a whole site it has to be divided into smaller units, which contain process units and utility units. The energy vectors around a production site can be schematically represented as in Figure 1.7.

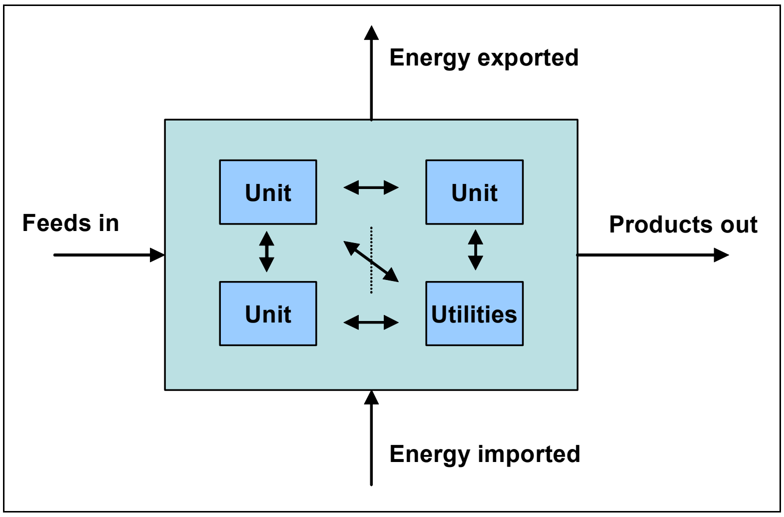


**Figure 1.7: Inputs and outputs of a site**

A production site may make different types of products, each having its own energy intensity factor. It is therefore not always easy to define a meaningful energy efficiency indicator for a site. The indicator may be the following:

$$EEI = \frac{\sum_{i-units} Pi,j * SEC_{refj}}{\text{Energy used by the site over period concerned}}$$

Where: $P_{i,j}$ = the sum of the products from the units

$SEC_{ref\,j}$ = the reference SEC for the products, j

**Utilities**

When dividing the production sites into production units (see Section 2.2.2), the utility centre should be considered in an accountable manner. When the utility centre produces utilities for more than one production unit it is usually considered as a separate (stand-alone) production unit. Equally, the utility may be supplied by other operator, e.g. see ESCOs, Section 5.1.10.

The utility section in itself may be divided into several sections: for instance, a part related to the storage and loading/unloading area, a part related to hot utilities (e.g. steam, hot water) and a part related to cold utilities (cooling water, $N_2$, compressed air). Section 1.5 discusses the calculation of energy vectors from utilities, in the discussion of primary and secondary energy.

The following equation should always be tested:

$$\text{Energy used by the site} = \sum_{i=\text{units}} \text{EIF}_i * P_i + \text{Energy used by utility section}$$

Where: $\sum_{i-units} SECi$ = The sum of the SECs for I units

**Different agglomeration of units in different sites**

An example is the case of gasoline hydrotreaters in a steam cracker. Gasoline is a co-product of a steam cracker (hence is counted in $P_2$ rather than $P_1$ in Figure 2.2). Before it can be added to the gasoline products, it needs however to be hydrotreated to saturate the olefins and diolefins present and to remove the sulphur components. Most operators would treat the gasoline hydrotreater as a separate unit of the steam cracker. However, in some sites the gasoline hydrotreater is integrated to the cracker so that, for simplicity purposes, it is sometimes included within the cracker system boundary. Not surprisingly, those crackers, which include the gasoline hydrotreater in their system boundary, will tend to have higher energy consumptions than those which do not. This, of course, does not imply that their energy efficiency is lower.

It can therefore be seen that for the implementation of energy management within the site, it is essential to:

- divide the site into its production units, including the exact system boundary of these production units (see also Section 1.5, below). The break-up of a site into production units will depend on the complexity of the production site and should be decided in each case by the operator responsible
- clearly define the energy flows in and out of the site and between the different production units (unit boxes in the Figure 1.7)
- maintain these defined boundaries unless changes are required or are driven, e.g, by changes to production and/or utilities; or, by moving to a different basis agreed at installation, company or sector level, etc.

This then clearly defines the way in which the energy efficiency of a given production process is calculated.

## 1.5 Issues to be considered when defining energy efficiency indicators

Section 1.3 discusses how to define energy efficiency and highlighted important related issues, such as primary and secondary energy. This section also introduced the concept of energy efficiency for utilities and/or systems. Sections 1.4.2 and 1.4.3 discuss how to develop energy efficiency indicators for a production unit and for a site from a top-down perspective, and discusses the problems encountered.

In the current section:

- Section 1.5.1 discusses the importance of setting the right system boundaries when optimising energy efficiency. It considers the relative impacts of the energy efficiency of the component parts and systems by taking a bottom-up approach
- Section 1.5.2 how to assess energy efficiency further important issues that can be decided by the operator and which should be taken into account in the definition of energy efficiency and indicators.

### 1.5.1 Defining the system boundary

[5, Hardell and Fors, 2005]

The following examples consider single components, sub-systems and systems, and examine (a) how the improvement in energy efficiency can be assessed. The examples are based on a typical company energy efficiency assessment. The example shows the effect of considering a system for a required utility at too low a level (component/constituent part or sub-system).

The thermodynamic efficiency is given in Section 1.2.2.1:

$$\text{Energy efficiency } \eta = \frac{\text{power output}}{\text{power input}} = \frac{\text{work W}}{\text{energy E}} \qquad \text{(usually expressed as \%)}$$

where:

work W is the amount of useful work done by the processor equipment (in joules)
energy E is the quantity of energy (in joules) used in the process

Improvement (change) in energy efficiency is:

$$\text{Improvement} = \frac{\text{change in energy used}}{\text{original energy usage}}$$

**System 1. Electric motor**

A company carried out a survey of existing motor drives. An old motor was found with an electrical power input of 100 kW. The efficiency of the motor was 90 % and, accordingly, the mechanical output power was 90 kW (see Figure 1.8).

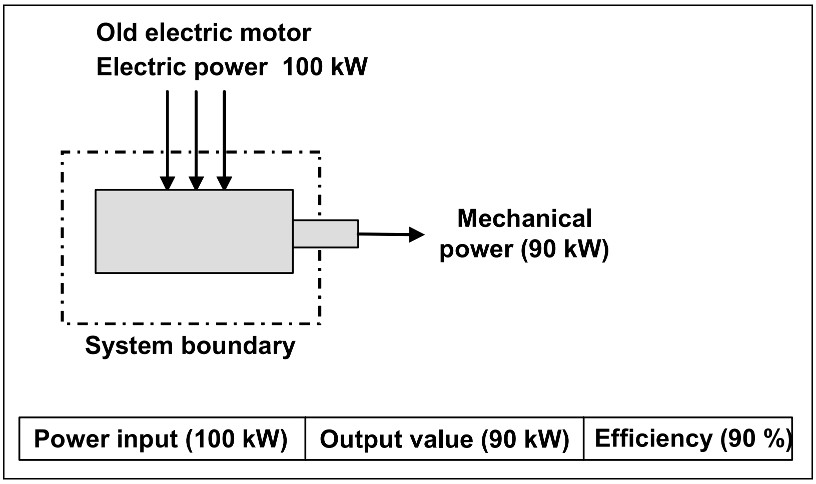


**Figure 1.8: System boundary – old electric motor**

### New electric motor

To improve the efficiency, the motor was replaced by a high efficiency motor. The effects of this change are shown in Figure 1.9. The electric power needed to produce the same output power, 90 kW, is now 96 kW due to the higher efficiency of the new motor. The energy efficiency improvement is thus 4 kW, or:

Energy improvement = 4/100 = 4 %

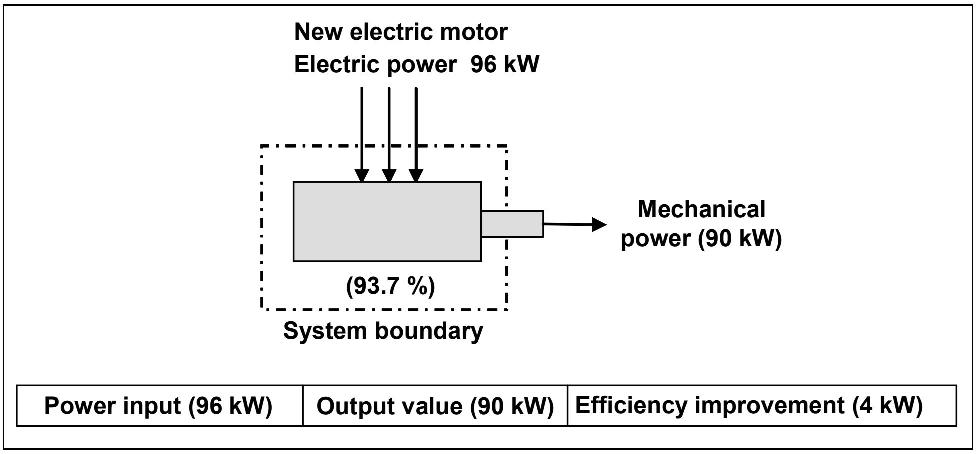


**Figure 1.9: System boundary – new electric motor**

## System 2: Electric motor and pump

As shown in Figure 1.10 an electric motor is used to operate a pump that provides cooling water for a cooling system. The combination of pump and drive is regarded here as one sub-system.

### New electric motor and old pump

The output value of this sub-system is the hydraulic power in the form of cooling water flow and pressure. Due to the low efficiency of the pump, the output value is limited to 45 kW.

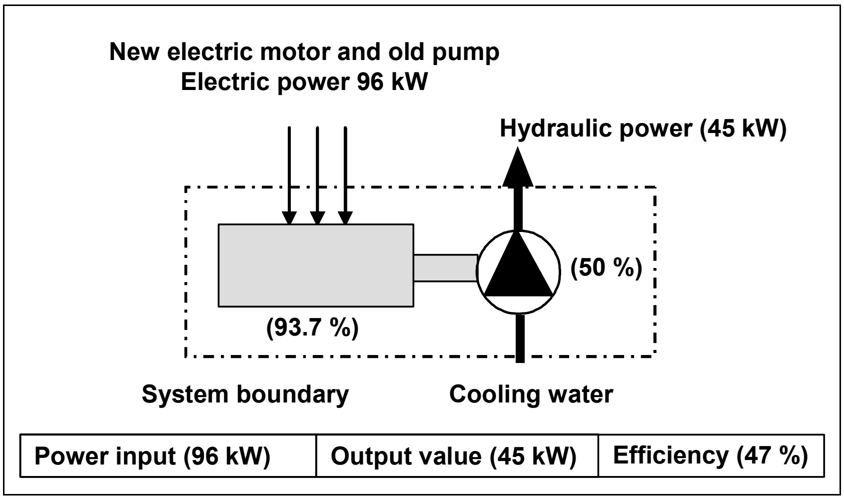


**Figure 1.10: System boundary – new electric motor + old pump**

New electric motor and new pump
The old pump is replaced by a new one, thereby increasing the pump efficiency from 50 to 80 %. The result of the replacement is shown in Figure 1.11.

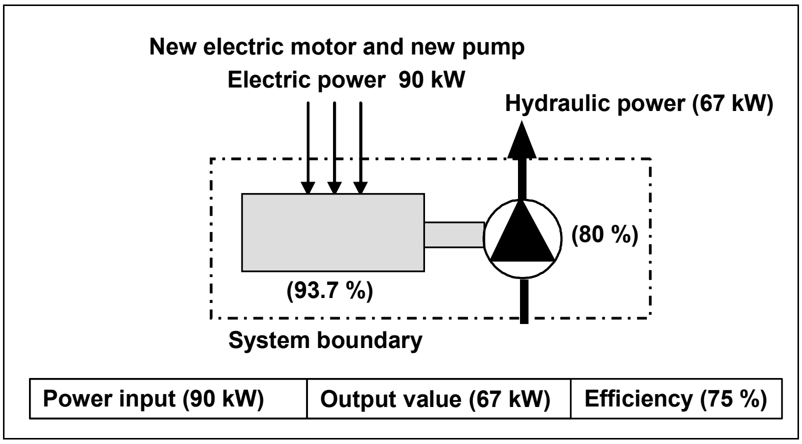


**Figure 1.11: System boundary – new electric motor + new pump**

The efficiency of the new sub-system is much higher than the previous one. The hydraulic power has increased from 45 to 67 kW. The increase in energy efficiency can be shown as (see Section 1.3.1):

$$\text{EEF} = \frac{\text{efficiency}}{\text{reference efficiency}} = \frac{75}{47} = 1.60\text{, i.e. 60 \% improvement in energy efficiency}$$

**System 3. New electric pump and new pump with constant output value**
As was indicated in Figure 1.10, the cooling system worked satisfactorily even at a hydraulic power of 45 kW. The benefit of an increase of the hydraulic power by 50 % to 67 kW is not clear, and the pumping losses may now have been transferred to a control valve and the piping system. This was not the intended aim of replacing the components by more energy efficient ones.

A comprehensive study of the cooling system may have shown that a hydraulic power of 45 kW was sufficient, and in this case, the shaft power can be estimated at 45/0.8 = 56 kW. The electric power needed to drive the motor would then be about 56/0.937 = 60 kW.

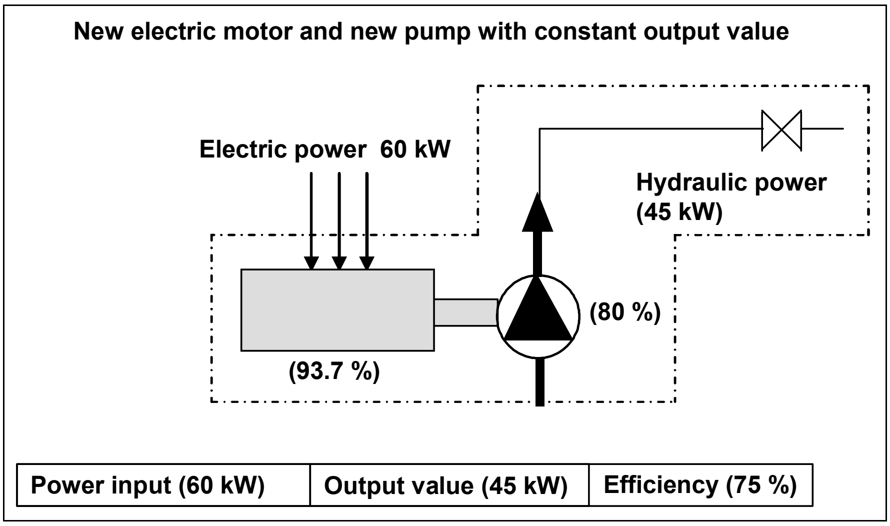


**Figure 1.12:** New electric motor + new pump with constant output

In this case, the power input was 40 kW lower than before, see Figure 1.8. The efficiency remains at 75 %, but the power consumption from System 1 (old motor and, presumably, old pump) is reduced by 40 %, and from System 2 (new motor, new pump).

The assessment could have investigated whether it was possible to reduce the size of both motor and pump without harmful effects on the cooling, or to reduce the required hydraulic power to, e.g. 20 kW. This may have reduced the capital money spent on equipment, and also shown an energy efficiency improvement.

**System 4. System 3 coupled with an heat exchanger**

In Figure 1.13, the system boundary has been extended and the sub-system now includes a new motor, a new pump and an old heat exchanger for the cooling process. The process cooling power is 13 000 $kW_{th}$ (th = thermal).

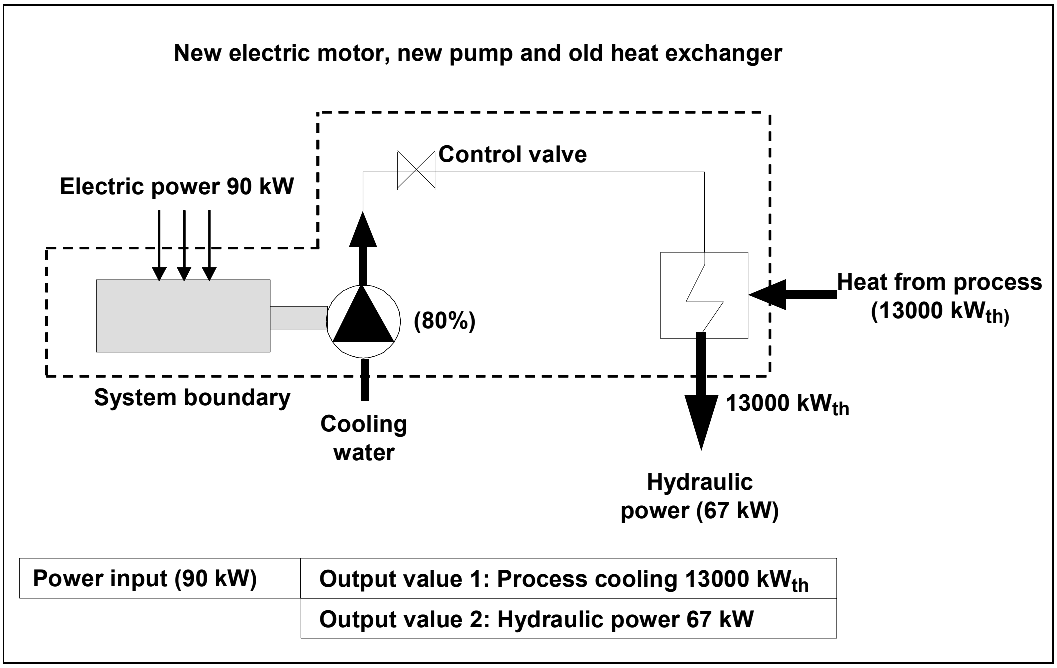


**Figure 1.13:** New electric motor, new pump and old heat exchanger

The output values are the removal of process heat and hydraulic power due to increased water flow and pressure.

However, in terms of defining this utility system (see Sections 1.3.1 and 1.4.1), the utility service provided is cooling. The system is designed to deliver cooling of 13 000 $kW_{th}$ to a process (or processes). The process heat in this system plays no part, and the output heat is wasted. *TWG – is this correct ?.* The efficiency remains as 75 %, as in System 3, if measured on an input/output basis. However, it could be measured on an SEC basis, and the energy required to deliver a specified amount of cooling (see Section 1.3.1):

$$\text{SEC} = \frac{\text{energy used}}{\text{products produced}} = \frac{\text{(energy imported – energy exported)}}{\text{products/outputs produced}}$$

$$= \frac{\text{energy used in cooling system}}{\text{service delivered}} = \frac{90 - 67\ \text{kW}}{13\ 000\ \text{kW}_{th}\ \text{cooling}}$$

$$= 0.00177\ \text{kW/kW}_{th}\ \text{cooling} \qquad = 1.77\ \text{W/kWth cooling}$$

If the cooling needs are reduced, e.g. caused by a cut back in production to 8000 kW cooling, then the SEC becomes 2.88 $W/kW_{th}$. As stated in Section 1.3.1, this is an increase in SEC, and therefore a loss in energy efficiency, i.e. a loss of:

$$\frac{(2.88 - 1.77)}{1.77} = 62\ \%$$

Note: this does not address the efficiency of the cooling of the process, only the energy efficiency of the cooling system.

**System 7: System 6 with recovery of heat**

Due to environmental concerns, a decision was taken by the company to reduce the emissions of carbon and nitrogen dioxides by recovering heat from the cooling water, thereby reducing the use of oil in the heating plant (see Figure 1.14):

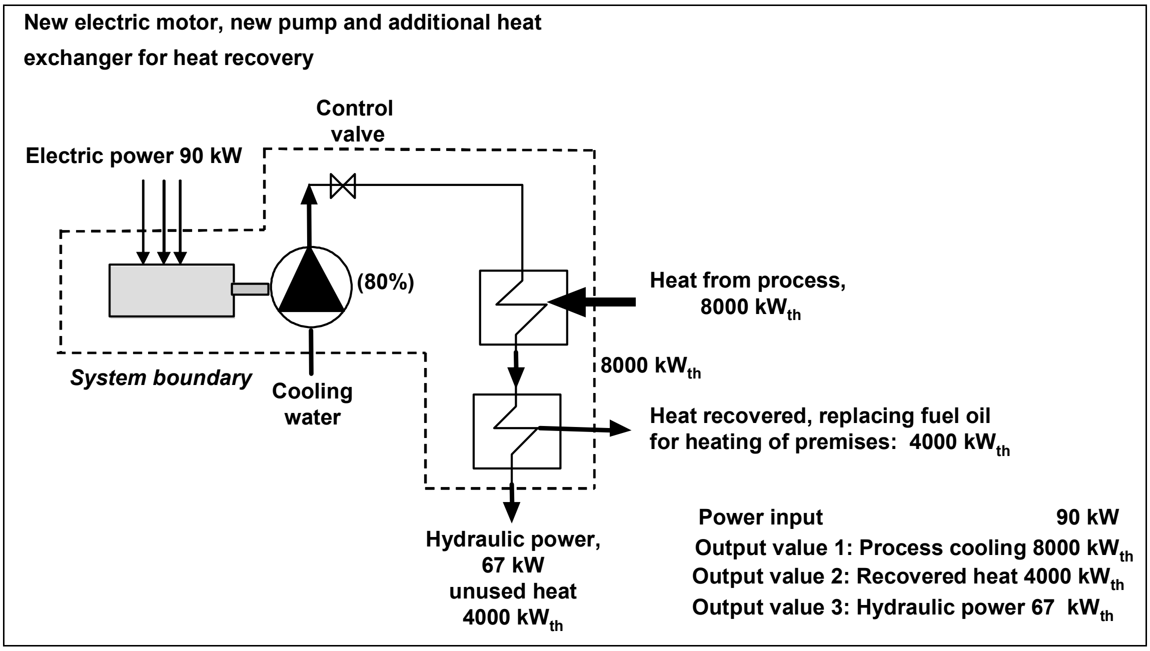


**Figure 1.14: New electric motor, new pump and two heat exchangers**

A calculation strictly on inputs and outputs to the cooling system shows:

$$\frac{\text{energy used in cooling system}}{\text{service delivered}} = \frac{90 - 67\ \text{kW}}{4000\ \text{kW cooling}}$$

$= 0.00575\ \text{kW/kW}_{th}$ cooling $= 5.75\ \text{W/kW}_{th}$ cooling.

Compared with calculations on System 6, this is a decrease in efficiency, while the oil-fired heating plant will show an increase in efficiency.

It is evident that the heat recovery arrangement represents an increase in energy efficiency. To estimate the value of the heat recovery in more detail, the oil-fired heating plant also needs to be considered. The value of the reduction of the oil consumption and the decreasing heat recovery from hot flue-gases from the heating plant need to be taken into account.

In this case, like in most others, the sub-systems are interconnected, which means that the energy efficiency of one sub-system often has an influence on the efficiency of another.

#### 1.5.1.1 Conclusions on systems and system boundaries

It is important to consider an installation in terms of its component units/systems. The maximum return on investment may be gained from considering a whole site and its inter-connected units/systems (for example, see the BAT 13 and 14 in the STS BREF, and BAT 81 for the coating of cars). Otherwise, (as seen in Systems 1 and 2 above) changing individual components may lead to investment in incorrectly sized equipment and missing the most effective efficiency savings.

Investigations should be carried out into the need for a given existing system or sub-system, or whether the required service (e.g. cooling, heating) can be achieved in a modified or totally different way to improve energy efficiency.

The units/systems must be:

- defined in terms of boundaries and interactions at the appropriate level
- seen to deliver an identifiable, needed service or product
- assessed in terms of the current or planned need for that product or service (i.e. not for past plans.

The maximum energy efficiency for an installation may mean that the energy efficiency of one or more systems may be de-optimised to achieve the overall maximum efficiency (this may be in mathematical terms, as efficiencies gained elsewhere or other changes may change the factors in the calculations for an individual system. It may not result in more energy usage). See Annex 2.

### 1.5.2 Other important issues to be considered at installation level

#### 1.5.2.1 Recording the reporting conventions used

At installation level, one practice for reporting should be adopted and maintained. The boundaries for energy efficiency calculations and any changes in boundaries and operational practices should be identified in the internal and external historical database. This will help maintain the interpretation and comparability between different years.

### 1.5.2.2 Internal production and use of energy

In several processes (e.g. refineries, black liquor in pulp and paper plants) fuel that is produced in the process is consumed internally. It is essential that the energy in this fuel is taken into account when looking at the energy efficiency of a process. Indeed, as shown in Section 2.2.2, refineries would have very low energy consumptions, as about 4 to 8 % of the crude oil input is used internally as liquid and gaseous fuels. In addition, refineries may also import energy resources such as electricity, steam and (occasionally) natural gas. The refinery may be equipped with a cogeneration facility, and may export electricity while increasing the internal fuel consumption. According to equation 1 and 3, a refinery equipped with a cogeneration facility could become a net energy producer.

Clearly this does not reflect reality, as refineries consume significant amounts of energy. While system boundaries and energy vectors can be chosen to reflect the circumstances at an installation, once defined for a specific plant, these should be adhered to.

### 1.5.2.3 Waste and flare recovery

Any process generates a quantity of solid, liquid and/or gaseous waste. These wastes may have an energy value which may be recovered internally or externally. The solid and liquid waste may be exported to an external incineration company, the waste gases may be flared.

Wastes
Example 1.1: A waste has previously been exported to an external incinerator company. The production site finds a way to use this waste internally, e.g. as fuel for its boilers or its furnaces and needs to determine whether this improves the energy efficiency of the production unit/site, given that:

- the internal use of this waste reduces the need for external fuels, but the overall energy consumption still stays the same
- on the other hand, the incinerator company may have an installation where the fuel value of that waste is recovered via the production of steam. In this case, the rerouting of the waste stream for use as an internal fuel rather than sending it to an incinerator company may not result in any overall improvement of the energy efficiency when looking at the total picture of the producer plus incinerator company.

Note: the switch from external incineration to internal use may be driven by commercial conditions and not energy efficiency.

See Overall, below for conclusions.

Flares
Flares are used to dispose of waste gases on plants such as mineral oil refineries, tanks farms, chemical plants and landfills. A flare is also a safety device and well maintained, operated and designed sites will have, under normal operating conditions, a small to negligible flow to flare. Most sites will, however, have a constant small flow to the flare due to e.g. leaking relief valves and venting due to loading/unloading operations of storage tanks.

Any gas sent to flare is burned without recovery of the energy contained in the flare gas. It is possible to install a flare gas recovery system, which recovers this small flow and recycles it to the site fuel gas system.

Example 1.2: A production process, which previously did not have a flare gas recovery system, decides to install one. This will reduce the external consumption of fuel gas, whereas the overall fuel gas consumption of the process remains the same. The operator needs to determine whether this fuel gas recovery system is considered. This is more important if one production process recovers not only its own flare losses but also the losses to flare of other production processes on the site.

See Overall, below for conclusions.

Overall

According to the equation in Section 1.4.2.2, no credit is shown directly for recovering waste as fuel. However, where it is recycled internally, it may be used to reduce the value of the fuel import ($E_{f, in}$). Where the energy is recovered at the external incinerator, the case is analogous to the calculation of primary energy (see Section 1.3.1) and may be allowed for in the same manner. However, the picture may become very complex, unless significant amounts of wastes containing energy are produced within the installation (proportionate to the energy input of the installation).

Another possibility is to define, for a given process, the reference practice on the amount of waste generated and to what extent it is recycled, and to give an energy credit to those operators who are able to use the waste in a more efficient way than the reference case.

From the above considerations, it should be clear that it is important to agree on the rules of how to deal with waste when setting up the framework to define the SEC/EEI of a process/unit Different industrial sectors may have different practices and valorise the internal use of waste in their energy efficiency. It is important that each industrial sector and/or company clearly defines the standard practice applied.

Each industry should define clearly how to deal with wastes, to allow a fair comparison between competing production processes. At installation level, one practice for reporting should be adopted and maintained. Changes should be identified in the internal and external historical database to maintain the comparability between different years.

### 1.5.2.4 Load factor (reduction of SEC with increasing production)

The reduction of the specific energy consumption with an increasing production rate is quite normal and is caused by two factors:

- the production equipment will be operating for longer periods when the production rate is high. This means that the idle periods become shorter. Some types of equipment run continuously, even during non-production times. This period will be reduced when the non-production time gets shorter
- there is a base energy consumption that does not depend on the utilisation of production capacity. This consumption is related to the starting up and maintaining temperature of equipment (without any production, see sensible heat, Section 1.5.2.8), the use of lighting, fans for ventilation, office machines, etc. The heating of the premises is also independent of the production rate but rather on the outdoor temperature, as is shown in Figure 1.15. At higher production rates, these consumptions will be spread over more (tonnes of) products.

To eliminate the influence of the load factor on the real energy efficiency of the site/unit, the operator may use sector/site/unit-specific correction factors. Equally, the base load of the site/unit may be measured, calculated or estimated (e.g. by extrapolating from different production rates). This situation is analogous to financial accounting, and the energy efficiency balances can be qualified in specific cases [127, TWG].

The operator should update its internal and external historical database to maintain the comparability between different years.

### 1.5.2.5 Changes in production technology and product development

Changes in production technology may be implemented, e.g. as a result of technical development, or because of new components or technical systems being available on the market. Obsolete technical systems may need to be replaced and new control systems may need to be introduced to improve the production efficiency. The introduction of such changes of production technology may also lead to improvements of energy efficiency. Changes in production technology leading to more efficient energy use will be regarded as measures for energy efficiency improvements. See Sections 2.2.3 and 2.2.3.1.

In some cases, new units may need to be added to a production process to meet the market demand, or to comply with new product specifications or with environmental requirements. In these cases, the SEC may deteriorate after the new unit has been put into operation, because the new unit requires additional energy. This does not mean that the site is failing in its management of energy.

In general, the operator should update their internal and external historical database to maintain the comparability between different years.

Examples:
1. New fuel specifications (for low sulphur diesel and gasoline set by the EURO IV regulation) required the adaptation of mineral oil refineries in the years 2000 – 2005. This led to an increase of energy consumption at the refineries.

2. In the pulp and paper industry, improvements to the fibres used in the process led to a reduction of energy use. At a later date, the quality of the finished product was also improved, which required increased grinding. After these two steps in technical development, the end result was an increase in the total energy use.

3. A steel industry can improve the strength of the delivered steel products; however, the new processes increase energy consumption. The customers can reduce the steel thicknesses in their products by several tens per cent. There may be energy gains from the decreased weight of the products e.g. in cars. This energy saving is part of the life cycle assessment of the products, and does not figure in the energy efficiency calculations for an installation (as the IPPC Directive does not include LCA of products).

**Changes in the production layout**
Changes in the production layout may mean e.g. that unprofitable production lines will be shut down, utility support systems will be changed, similar lines of business will be merged. Changes in production layout may also be made to achieve energy efficiency improvements.

This may impact on the SEC denominator, and the operator should update their internal and external historical database to maintain the comparability between different years.

**Ceasing of the manufacturing of a product with high energy input**
A company may cease manufacturing a product that requires a high energy input. Both the total and the specific energy consumption will be reduced. This may be claimed to be a measure to improve the energy efficiency although no other measures have been taken.

Again, the operator should update their internal and external company historical database according to the actual product package to maintain the comparability between different years.

**Outsourcing**

The supply of a utility is sourced out side of the installation, e.g. the generation and supply of compressed air (see Section 3.7). The energy consumption would be reduced by buying compressed air from an external source. The energy use of the supplier of compressed air will be increased. The change should be dealt with as described in primary energy Section 1.3.5.1.

**Contracting out of process steps**

An operator may consider contracting out a process that is energy intensive, such as heat treatment of metal components. As the operation still has to be carried out, it cannot be regarded as an action for energy efficiency improvements, and should be included in calculations, unless the change is noted in records and the SEC/EEF is amended accordingly. Note: a sub-contractor running such a process may be more energy efficient, as there may be more expert knowledge of the process (enabling better process optimisation) and there may be higher throughput, reducing the load factor.

Examples: An operator of an installation for the serial construction of cars decides to increase their purchase of components instead of manufacturing such components themselves. The result will be that the total and the specific energy consumption will decrease. This must be taken into account in the updating of energy efficiency indicators and records.

### 1.5.2.6 Energy integration

**1. Internal power production**

Internal power production without increasing the use of primary energy sources is a recognised way of improving energy efficiency. This can be optimised by the exchange of energy with adjacent units or installations (or non-industrial users). System boundaries need to be defined and possible ambiguities settled. The setting of boundaries are discussed in Sections 1.4 and 1.5 above, and calculating primary energies in Section 1.3.5.1.

**2. Use of oxygen in a combustion plant**

Oxygen may be used as in a combustion plant to increase combustion efficiency and reduce fuel inputs. It also has a beneficial effect on the energy efficiency by reducing the air mass flow in the flue-gases, and reduced $NO_X$ emissions. However, energy is also used in the production of $O_2$, and this should be accounted for. This is discussed under primary energy (Section 1.3.5.1) and in Annex 8, Glass Industry.

**3. Process integration and company disaggregation**

Over the last few decades, two trends can be observed:

- the integration of processes
- the disaggregation of companies, especially in the chemicals sector.

The development of sites with a high degree of integration offers considerable economic advantages. In other cases, the market strategy has been to break companies into their component production entities. In both cases, this results in complex sites with many operators present and with the utilities being generated either by one of these operators or even by a third party. It may also result in complex energy flows between the different operators.

In general, these large integrated complexes offer a high potential for an efficient use of energy through integration.

However, as noted in Sections 1.4 and 1.5, special care is required when defining the system boundaries for energy efficiency for such complex sites. It is emphasised that in an isolated examination of individual production processes, certain energy uses might seem inefficient even though they constitute a highly efficient approach within the integrated system of the site. Individual operators not able to operate at the best efficiency for their unit may be commercially compensated in order to achieve the most competitive environment for the integrated site as a whole.

Some examples are:

- the use of steam in a drying process appears to be less energy efficient than the direct use of natural gas. However, the low pressure steam comes from a CHP process combined with highly efficient electricity generation
- cogeneration plants located at the production site are not always owned by the production site, but may be a joint venture with the local electricity generation company. The steam is owned by the site operator and the electricity is owned by the electricity company. Care should therefore be taken in how these facilities are accounted for
- electricity is generated and consumed at the same site, however much lower transmission losses are expected
- within a highly integrated system, residues containing energy from production processes are returned into the energy cycle. Examples are the return of waste heat steam into the steam network, the use of hydrogen from the electrolysis process as a fuel substitute gas in the power plant process or as a chemical (e.g. raw material in hydrogen peroxide production), and the incineration of production residues in power plant boilers.

#### 1.5.2.7 Heating and cooling of premises

The heating and cooling of premises is an energy use that is strongly dependent on the outdoor temperature, as is shown in Figure 1.15.

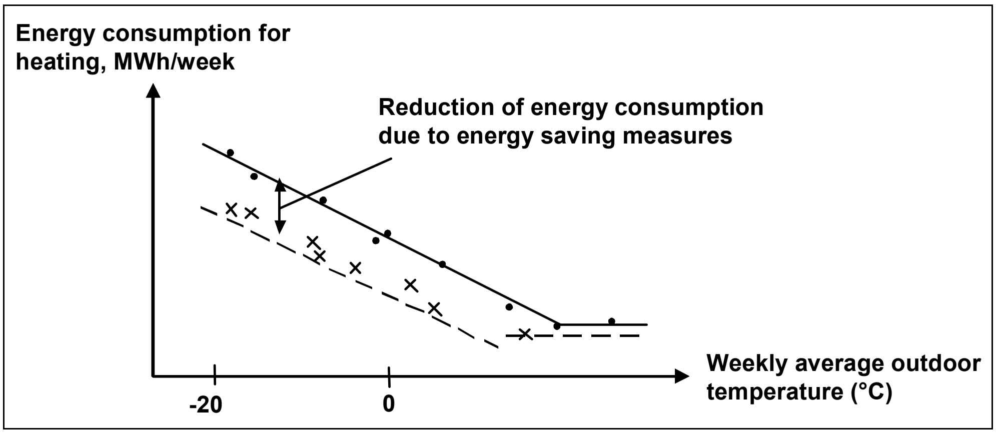


**Figure 1.15: Energy consumption depending on outdoor temperature**

If measures such as heat recovery from the outlet of ventilation air or improvement of building insulation are taken, the line in Figure 1.15 will move downwards.

The heating and cooling requirements are therefore independent of production throughput and form part of the load factor (discussed above). It is also a regional factor, generally with heating requirements being greater in Northern Europe, and cooling greater in Southern Europe. This can affect the production processes, e.g. the need to keep waste at a treatable temperature in waste treatment installations in Finland in winter, the need to keep food products fresh will require more cooling in Southern Europe, etc.

### 1.5.2.8 Sensible heat

In Example 4 in Annex 2, the heating requirement to bring all plant input from ambient temperature to 104.4°C in a refinery is called the **sensible heat**. The basis for the plant input is all gross raw material input streams (and their respective densities) that are 'processed' in process units. Blend stocks are not taken into account. Annex 2 lists further examples of

- processes:
    - Example 1: mineral oil refineries:
    - Example 2: ethylene cracker
    - Example 3: vinyl acetate monomer (VAM) production
    - Example 4: steel rolling mill

- These processes illustrate the following issues:
    - varied and complex sites
    - complex energy flows,
    - multiple products with fuel values.
    - specific industry-wide SEC for refineries, the Solomon Energy Benchmark
    - electrical energy efficiency varying with production

# 2 TECHNIQUES TO CONSIDER IN ACHIEVING ENERGY EFFICIENCY AT AN INSTALLATION LEVEL

[6, Cefic, 2005], [9, Bolder, 2003], [89, European Commission, 2004], [92, Motiva Oy, 2005], [96, Honskus, 2006], [108, Intelligent Energy - Europe, 2005][127, TWG]

A hierarchical approach has been used for Chapters 2 and 3:

- Chapter 2 describes techniques to be considered at the level of a entire installation with the potential to achieve optimum energy efficiency
- Chapter 3 sets out techniques to be considered at a level below installation: primarily the level of energy-using systems (e.g. compressed air, steam) or activities (e.g. combustion), and subsequently at the lower level for some energy-using component parts or equipment (e.g. motors).

Management systems, process-integrated techniques and specific technical measures are included in the two chapters, but these three overlap completely when seeking the optimum results. Many examples of an integrated approach demonstrate all three types of measures. This makes the separation of techniques for description somewhat difficult and arbitrary.

Neither this chapter nor Chapter 3 gives an exhaustive list of techniques and tools, and other techniques may exist or be developed which may be equally valid within the framework of IPPC and BAT. Techniques may be presented singly or as combinations (both from this chapter and Chapter 3) and supported by information in Chapter 1 to achieve the objectives of IPPC.

Where possible, a standard structure is used to outline each technique in this chapter and in Chapter 3, as shown in Table 2.1. Note that this structure is also used to describe the systems under consideration, such as (at installation level) energy management, and (at a lower level) compressed air, combustion, etc.

| Type of information considered | Type of information included |
|---|---|
| Description | Short descriptions of energy efficiency techniques presented with figures, pictures, flow sheets, etc. that demonstrate the techniques |
| Achieved environmental benefits | The main environmental benefits supported by the appropriate measured emission and consumption data. In this document, specifically the increase of energy efficiency, but including any information on reduction of other pollutants and consumption levels |
| Cross-media effects | Any side-effects and disadvantages caused by implementation of the technique. Details on the environmental problems of the technique in comparison with others |
| Operational data | Performance data on energy and other consumptions (raw materials and water) and on emissions/wastes. Any other useful information on how to operate, maintain and control the technique, including safety aspects, operability constraints of the technique, output quality, etc. |
| Applicability | Consideration of the factors involved in applying and retrofitting the technique (e.g. space availability, process specific) |
| Economics | Information on costs (investment and operation) and related energy savings, EUR kWh (thermal and/or electricity) and other possible savings (e.g. reduced raw material consumption, waste charges) also as related to the capacity of the technique |
| Driving force for implementation | Reasons (other than IPPCD) for implementation of the technique (e.g. legislation, voluntary commitments, economic reasons) |
| Examples | Reference to at least one situation where the technique is reported to be used |
| Reference information | Sources of information and literature for more details on the technique |

**Table 2.1: The information breakdown for systems and techniques described in Chapters 2 and 3**

## 2.1 Energy efficiency management systems (E2MS)

### Description

All industrial companies can save energy by applying the same sound management principles and techniques they use elsewhere in the business for key resources such as finance, raw material and labour as well as for environment and health and safety. These management practices include full managerial accountability for energy use. The management of energy consumption and costs eliminates waste and brings cumulative savings over time.

Note that some energy management techniques that secure financial savings do not reduce energy usage (see Section 5.2)

The best environmental performance is usually achieved by the installation of the best technology and its operation in the most effective and efficient manner. This is recognised by the IPPC Directive definition of ‘techniques’ as *“both the technology used and the way in which the installation is designed, built, maintained, operated and decommissioned”*.

For IPPC installations an Environmental Management System (EMS) is a tool that operators can use to address these design, construction, maintenance, operation and decommissioning issues in a systematic, demonstrable way. An EMS includes the organisational structure, responsibilities, practices, procedures, processes and resources for developing, implementing, maintaining, reviewing and monitoring the environmental policy. Environmental Management Systems are most effective and efficient where they form an inherent part of the overall management and operation of an installation.

Management to achieve energy efficiency similarly requires structured attention to energy with the objective of continuously reducing energy consumption and improving efficiency in production and utilities, and sustaining the achieved improvements at both at company and site level. It provides a structure and a basis for the determination of the current energy efficiency, defining possibilities for improvement and ensuring continuous improvement. All effective energy efficiency (and environmental) management standards, programmes and guides contain the notion of continuous improvement meaning that energy management is a process, not a project which eventually comes to an end.

There are various process designs, but most management systems are based on the plan-do-check-act cycle (which is widely used in other company management contexts). The cycle is a re-iterative dynamic model, where the completion of one cycle flows into the beginning of the next, see Figure 2.1.

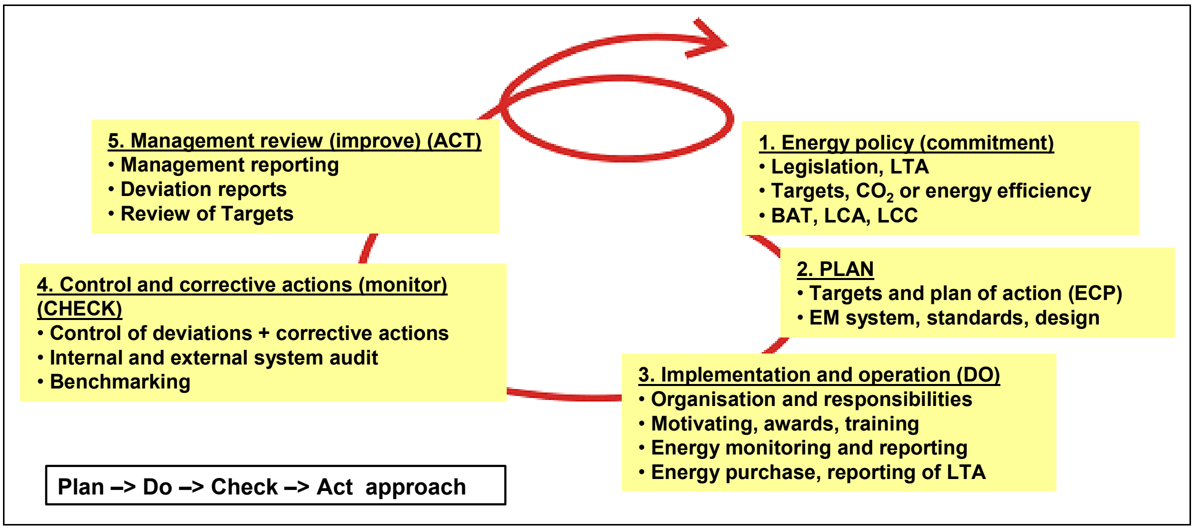


**Figure 2.1: Continuous improvement of an energy efficiency management system**
**[92, Motiva Oy, 2005]**

The best performance has been associated with energy management systems that show the following: (from Energy management matrix, [107, UK Good Practice Guide, 2004])

- **energy policy** – energy policy, action plans and regular reviews have the commitments of top management as part of an environmental strategy
- **organising** – energy management fully integrated into management structure. Clear delegation of responsibility for energy consumption
- **motivation** – formal and informal channels of communication regularly exploited by energy manager and energy staff at all levels
- **information systems** – a comprehensive system sets targets, monitors consumption, identifies faults, quantifies savings and provides budget tracking
- **marketing** – marketing the value of energy efficiency and the performance of energy management both within and outside the organisation
- **investment** – positive discrimination in favour of 'green' schemes with detailed investment appraisal of all new-build and refurbishment opportunities.

From these sources, it can be seen that an energy efficiency management system (E2MS) for an IPPC installation should contain the following components:

(a) commitment of top management
(b) definition of an energy efficiency policy
(c) planning and establishing objectives and targets
(d) implementation and operation of procedures
(e) benchmarking
(f) checking and corrective action
(g) management review
(h) preparation of a regular energy efficiency statement
(i) validation by certification body or external energy efficiency verifier
(j) design considerations for end-of-life plant decommissioning
(k) development of energy efficient technologies.

These features are explained in greater detail below. Detailed information on components (a) to (k), is given in the Reference information, below. Examples are given in Annex 3.

### (a) Commitment of top management

The commitment of top management is the precondition for successful energy efficiency management. Top management should:

- place energy efficiency high on the company agenda, make it visible and give it credibility
- identify one top manager with responsibility for energy efficiency (this need not be the person responsible for energy, by analogy to quality management systems)
- help create an energy efficiency culture and create the necessary driving forces for implementation
- define a strategy (long term visions) to achieve energy efficiency within integrated pollution prevention and control objectives
- set company targets to achieve these energy efficiency objectives with the IPPC objectives
- define short and medium term concrete actions to achieve the long term vision
- provide the platform to integrate decision-making in order to achieve integrated pollution prevention including energy saving, particularly for when planning new installations or significant upgrading
- guide the company to make investment and purchasing decisions that achieve integrated pollution prevention coupled with energy saving on a continuing basis. Integrated pollution prevention and control is achieved through integrated decision-making and actions, including the buying of utilities and capital equipment, planning, production, and maintenance as well as environmental management
- define an energy efficiency policy, see (b) below.

### (b) Definition of an energy efficiency policy

Top management are responsible for defining an energy efficiency policy for an installation and ensuring that it:

- is appropriate to the nature, scale and energy use of the activities carried out at the installation
- includes a commitment to energy efficiency within IPPC
- includes a commitment to comply with all relevant legislation and regulations applicable to energy efficiency, and with other requirements (including energy agreements) to which the organisation subscribes
- provides the framework for setting and reviewing energy efficiency objectives and targets
- is documented and communicated to all employees
- is available to the public and all interested parties.

### (c) Planning and establishing objectives and targets

- procedures to identify the energy efficiency aspects of the installation and to keep this information up-to-date
- procedures to evaluate proposals for new processes, units and equipment, upgrades, rebuilds and replacements in order to identify the energy efficiency aspects and to influence the planning and purchasing to optimise energy efficiency and IPPC
- procedures to identify and have access to legal and other requirements to which the organisation subscribes and that are applicable to the energy efficiency aspects of its activities
- establishing and reviewing documented energy efficiency objectives and targets, taking into consideration the legal and other requirements and the views of interested parties
- establishing and regularly updating an energy efficiency management programme, including designation of responsibility for achieving objectives and targets at each relevant function and level as well as the means and timeframe by which they are to be achieved.

### (d) Implementation and operation of procedures

It is important to have systems in place to ensure that procedures are known, understood and complied with, therefore effective energy management includes:

(i) Structure and responsibility
- defining, documenting, reporting and communicating roles, responsibilities and authorities, which includes appointing one specific management representative (in addition to a top manager (see (a) above)
- providing resources essential to the implementation and control of the energy management system, including human resources and specialised skills, technology and financial resources

(ii) Training, awareness and competence
- identifying training needs to ensure that all personnel whose work may significantly affect the energy efficiency of the activity have received appropriate training.

(iii) Communication
- establishing and maintaining procedures for internal communication between the various levels and functions of the installation,. It is particularly important that all individuals and teams that have a role in energy efficiency should have established procedures for maintaining contact, especially those buying energy-using utilities, capital equipment, as well as those responsible for production, maintenance and planning
- establishing procedures that foster a dialogue with external interested parties and procedures for receiving, documenting and, where reasonable, responding to relevant communication from external interested parties

(iv) Employee involvement

- involving employees in the process aimed at achieving a high level of energy efficiency by applying appropriate forms of participation such as the suggestion-book system, project-based group works or environmental committees

(v) Documentation

- establishing and maintaining up-to-date information, in paper or electronic form, to describe the core elements of the management system and their interaction and to provide references to related documentation

(vi) Efficient process control

- adequate control of processes under all modes of operation, i.e. preparation, start-up, routine operation, shutdown and abnormal conditions.
- identifying the key performance indicators for energy efficiency and methods for measuring and controlling these parameters (e.g. flow, pressure, temperature, composition and quantity)
- optimising these parameters for energy efficient operation
- documenting and analysing abnormal operating conditions to identify the root causes and then addressing these to ensure that events do not recur (this can be facilitated by a 'no-blame' culture where the identification of causes is more important than apportioning blame to individuals)

(vii) Maintenance

- establishing a structured programme for maintenance based on technical descriptions of the equipment, norms etc. as well as any equipment failures and consequences
- supporting the maintenance programme by appropriate record keeping systems and diagnostic testing
- identifying from routine maintenance, breakdowns and/or abnormalities possible losses in energy efficiency, or where energy efficiency could be improved
- clearly allocating responsibility for the planning and execution of maintenance

(viii) Emergency preparedness and response

- consider energy usage when recovering or reworking raw materials or products affected by emergency situations

**(e) Benchmarking, i.e.:**

- carrying out systematic and regular comparisons with sector, national or regional benchmarks

**(f) Checking and corrective action, i.e.** (see also benchmarking (e)):

(i) Monitoring and measurement

- establishing and maintaining documented procedures to monitor and measure, on a regular basis, the key characteristics of operations and activities that can have a significant impact on energy efficiency, including the recording of information for tracking performance, relevant operational controls and conformance with the installation's energy efficiency objectives and targets
- establishing and maintaining a documented procedure for periodically evaluating compliance with relevant energy efficiency legislation, regulations and agreements

(ii) Corrective and preventive action

- establishing and maintaining procedures for defining responsibility and authority for handling and investigating non-conformance with permit conditions, other legal requirements and commitments as well as objectives and targets, taking action to mitigate any impacts caused and for initiating and completing corrective and preventive action that are appropriate to the magnitude of the problem and commensurate with the energy efficiency impact encountered

(iii) Records and reporting

- establishing and maintaining procedures for the identification, maintenance and disposition of legible, identifiable and traceable energy efficiency records, including training records and the results of audits and reviews
- establishing regular reporting to the identified person(s) on progress towards energy efficiency targets

(iv) Audit

- establishing and maintaining (a) programme(s) and procedures for periodic energy efficiency management system audits that include discussions with personnel, inspection of operating conditions and equipment and reviewing of records and documentation and that results in a written report, to be carried out impartially and objectively by employees (internal audits) or external parties (external audits), covering the audit scope, frequency and methodologies, as well as the responsibilities and requirements for conducting audits and reporting results, in order to determine whether or not the energy efficiency management system conforms to planned arrangements and has been properly implemented and maintained
- completing the audit or audit cycle, as appropriate, at intervals of no longer than three years, depending on the nature, scale and complexity of the activities, the significance of energy use, associated environmental impacts, the importance and urgency of the problems detected by previous audits and the history of any energy inefficiency or problems – more complex activities with a more significant environmental impact are audited more frequently
- having appropriate mechanisms in place to ensure that the audit results are followed up

(v) Periodic evaluation of compliance with legalisation and agreements, etc.

- reviewing compliance with the applicable energy efficiency legislation, the conditions of the environmental permit(s) held by the installation, and any energy efficiency agreements
- documentation of the evaluation.

### (g) Management review, i.e.:

- reviewing, by top management, at intervals that it determines, the energy efficiency management system, to ensure its continuing suitability, adequacy and effectiveness
- ensuring that the necessary information is collected to allow management to carry out this evaluation
- documentation of the review

### (h) Preparation of a regular energy efficiency statement:

- preparing an energy efficiency statement that pays particular attention to the results achieved by the installation against its energy efficiency objectives and targets. It is regularly produced – from once a year to less frequently depending on the significance of energy use, etc. It considers the information needs of relevant interested parties and it is publicly available (e.g. in electronic publications, libraries etc.)

When producing a statement, the operator may use relevant existing energy efficiency performance indicators, making sure that the indicators chosen:

i. give an accurate appraisal of the installation's performance
ii. are understandable and unambiguous
iii. allow for year on year comparison to assess the development of the energy efficiency performance of the installation
iv. allow for comparison with sector, national or regional benchmarks as appropriate
v. allow for comparison with regulatory requirements as appropriate

### (i) Validation by certification body or external EEMS verifier:

- having the energy efficiency management system, audit procedure and policy statement examined and validated by an accredited certification body or an external verifier can, if carried out properly, enhance the credibility of the system

### (j) Design considerations for end-of-life plant decommissioning

- giving consideration to the environmental impact from the eventual decommissioning of the unit at the stage of designing a new plant, as forethought makes decommissioning easier, cleaner and cheaper
- decommissioning poses environmental risks for the contamination of land (and groundwater) and generates large quantities of solid waste. Preventive techniques are process-specific but general considerations, but when selecting energy efficient techniques, may include:
  i. avoiding underground structures
  ii. incorporating features that facilitate dismantling
  iii. choosing surface finishes that are easily decontaminated
  iv. using an equipment configuration that minimises trapped chemicals and facilitates drain-down or washing
  v. designing flexible, self-contained units that enable phased closure
  vi. using biodegradable and recyclable materials where possible
  vii. avoiding the use of hazardous substances, such as in heat exchanging or insulating fluids, etc.

### (k) Development of energy efficient technologies:

- energy efficiency should be an inherent feature of any process design activities carried out by the operator, since techniques incorporated at the earliest possible design stage are both more effective and cheaper (see Section 2.2.3). Giving consideration to the development of energy efficient technologies can for instance occur through R&D activities or studies. As an alternative to internal activities, arrangements can be made to keep abreast with – and where appropriate – commission work by other operators or research institutes active in the relevant field.

*TWG; Moved standard text on standardised EMS to Applicability*

**Achieved environmental benefits**

Implementation of and adherence to an E2MS focuses the attention of the operator on the energy efficiency performance of the installation. In particular, the maintenance of and compliance with clear operating procedures for both normal and abnormal situations and the associated lines of responsibility should ensure that the installation's permit conditions and other energy efficiency targets and objectives are met at all times.

Energy efficiency management systems typically ensure the continuous improvement of the energy efficiency performance of the installation. The poorer the starting point is, the more significant short-term improvements can be expected. If the installation already has a good overall energy efficiency performance, the system helps the operator to maintain the high performance level.

**Cross-media effects**

Energy efficiency management techniques should be designed to integrate with other environmental objectives and consider the overall environmental impact, which is consistent with the integrated approach of the IPPC Directive. However, energy efficiency is likely to one of several objectives to meet, and others (such as saving of raw materials, improved product quality, reduction of emissions to the environment may increase energy consumption. This is discussed further in the BREF on Economics and Cross-media

**Operational data**

No specific information reported. See Examples, below.

**Applicability**

**1.** Components

The components described above can typically be applied to all IPPC installations. The scope (e.g. level of detail) and nature of the E2MS (e.g. standardised or non-standardised) will generally be related to the nature, scale and complexity of the installation, and the energy usage, as well as the range of other environmental impacts it may have.

**2.** Standardised and non-standardised EMS and/or E2MSs

Within the European Union, many organisations have decided on a voluntary basis to implement energy management systems. These may be:

- adding specific requirements for energy efficiency to an existing management system, usually (but not exclusively) an EMS. An EMS may be based on EN ISO 14001:1996 or the EU Eco-management and audit scheme EMAS. EMAS includes the management system requirements of EN ISO 14001, but places additional emphasis on legal compliance, environmental performance and employee involvement; it also requires external verification of the management system and validation of a public environmental statement. In EN ISO 14001 self-declaration is an alternative to external verification. There are also many organisations that have decided to put in place non-standardised EMSs.
- using separate energy efficiency management systems. These may be:
  - energy management based on national standards (such as the Danish DS 2403, the Irish IS 393, the Swedish SS627750, the German VDI Richtlinie No. 46 Energy Management) or other guidelines (international standards or guidelines on energy management). A European (CEN) standard is in preparation
  - energy management system on a non-standardised basis and adapted to meet their own needs and management structures

A review of benchmarking and energy management schemes has found [165, BESS_EIS]:

- *Advantages of a standardised system* (e.g. Denmark DS 2403):
    - structured approach, concentrates on energy, easily achieved if ISO or other management system already in place
    - structure and terminology parallel to ISO 14001 and ISO 9001
    - proved energy savings in Denmark 10 to 15 %
    - energy efficiency becomes organisational requirement by top management
    - certification issued after approval
    - large companies prefer certified or structured management systems
    - the certification process is valuable, challenging and detailed
    - covers all topics of energy supply, transformation, use, behaviour, technology, people
    - well-documented (ISO 9001 based)
    - can be used in any energy agreements

- *Disadvantages:*
    - in itself, only guarantees a minimum energy management level
    - the degree to which companies implement e.g. DS 2403 varies
    - the focus for the companies is to satisfy the system, not to implement best practice in energy management
    - if no formal documented management system is in place, it will require additional resources and expertise to implement.

Implementation and adherence to an internationally accepted standardised system such as EN ISO 14001:1996 can give higher credibility to the EMS, especially when subject to a properly performed external verification. EMAS provides additional credibility due to the interaction with the public through the environmental statement and the mechanism to ensure compliance with the applicable environmental legislation. However, non-standardised systems can in principle be equally effective provided that they are properly designed and implemented.

However, non-standardised systems can in principle be equally effective provided that they are properly designed and implemented

**3.** External verification

Depending on the chosen system, the operator may opt (or not) to have external verification and/or a public energy statement

**Economics**

It is difficult to accurately determine the costs and economic benefits of introducing and maintaining a good EMS. However, it should be remembered that savings (net) contribute directly to gross profit.

See Examples, below.

**Driving forces for implementation**

Energy efficiency management systems can provide a number of advantages, for example:

- improved insight into the energy efficiency aspects of the company
- improved energy efficiency performance and compliance with energy efficiency measures (voluntary or regulatory)
- improved competitiveness, in particular against a trend of increasing energy prices
- additional opportunities for operational cost reduction and product quality improvement
- improved basis for decision-making
- improved motivation of personnel
- improved company image
- increased attractiveness for employees, customers and investors
- increased trust of regulators, which could lead to reduced regulatory oversight
- facilitates the use of liberalised energy markets, emerging energy services, energy agreements, and energy efficiency incentives (See Chapter 5), etc.

**Examples** (see Annex 3)

Outokumpu, Tornio works, Finland [160, Aguado, 2007]
Aughinish Alumina (AAL), Ireland [161, SEI, 2006]
Dow Chemical Company [163, Dow, 2005]
Proved energy savings in Denmark [165, BESS_EIS]

**Reference information**

[160, Aguado, 2007, 161, SEI, 2006, 163, Dow, 2005]

**1.** Key environmental standards

(Regulation (EC) No 761/2001 of the European parliament and of the council allowing voluntary participation by organisations in a Community eco-management and audit scheme (EMAS), OJ L 114, 24/4/2001, http://europa.eu.int/comm/environment/emas/index_en.htm)

(EN ISO 14001:1996, http://www.iso.ch/iso/en/iso9000-14000/iso14000/iso14000index.html; http://www.tc207.org)

**2** Energy efficiency standards

IS 393:2005 Energy management Systems (Ireland)
DS2403 Energy management Systems (Denmark)
SS627750 Energy management Systems (Sweden)

**Achievements:** (see Annex 3)

Dow achieved the targeted 20 % reduction in energy intensity, down from 13 849 kJ/kg of product to 11 079 kJ/kg, measured as kg of total DOW product mix.

# 2.2 Planning and establishing of objectives and targets

## 2.2.1 Continuous environmental improvement and cross-media issues

**Description**

A study in the 1990s has shown that many companies ignore apparently very good returns on energy investments. The conclusion was that most companies made a clear distinction between 'core' and 'non-core' business with little management effort devoted to the latter, unless opportunities survived very high hurdles, such as payback periods of 18 – 24 months. For businesses which are not energy intensive, energy costs were either regarded as 'fixed overheads' or ignored as falling below a 'threshold' share of costs. Also, companies with more significant energy costs did not appear to exploit the available opportunities for 'no regrets' investment. [166, DEFRA, 2003]

In order to achieve an integrated approach to pollution control, it is important to include continuing environmental improvement as a focus in the business planning for an installation. This includes short, medium and long term planning and all the component processes and/or systems of the installation.

An important element of an environmental management system (EMS, which is BAT in all IPPC sectors) is maintaining overall environmental improvement. It is essential that the operator understands what happens to the inputs (understanding the process), and how their consumption leads to emissions. It is equally important that when controlling significant inputs and outputs to maintain the correct balance between emissions reduction and cross-media effects, such as energy, water and raw materials consumption. This reduces the environmental footprint of the installation.

Energy efficiency is given a high degree of importance in EU policy (in statements such as the Berlin Declaration, where it is the only environmental issue raised [141, EU, 2007]). In considering the economics and cross-media effects of implementing BAT within an installation, the importance of energy efficiency should be taken into account when considering the requirements of Art 10 (4), i.e. the permit ELVs and equivalent parameters.

**Achieved environmental benefits**

Long-term reduction in consumptions of energy, water and raw materials, and emissions.

**Cross-media effects**

A part of the operation's consumptions or emissions may be higher proportionately for a period until longer term investment is realised.

**Operational data**

All significant consumptions (including energy) and emissions should be managed in a co-ordinated manner for the short, medium and long term, in conjunction with financial planning and investment cycles, i.e. adapting short-term end-of-pipe solutions to emissions may tie the operator to long term higher energy consumption, and postpone investment in more environmentally beneficial solutions. This will require some consideration of the cross-media issues, and guidance on these and the costing and cost-benefits issues is given in the ECM REF [167, EIPPCB, 2006], and in Energy Efficient Design and other subsections (Section 2.2.2 etc.).

**Applicability**

All IPPC installations. The extent of this exercise will depend on the installation size, and the number of the variables. A full cross-media study is carried out infrequently.

**Economics**
Enabling capital investment to be made in an informed manner for the reduction of the overall environmental benefit and the best value for money.

**Driving forces for implementation**
Cost reduction in the short, medium and long term.

**Examples**
An example of considering the cross-media effects is given in the ECM REF [167, EIPPCB, 2006].

A theoretical example is A vehicle manufacturer is seeking to reduce solvent emissions further. A large step change can be achieved, but this requires replacement of the entire paintshop, which has an operating life of 25 years and a capital cost of about EUR 500 000. The energy consumption of the paintshop is about 38 - 52 % of the entire power consumption of the plant and in the order of 160 000 – 240 000 MWh (of which 60 % is gas). The amount of raw material used, the application efficiency and the amount of solvents lost may also be affected by the degree of automation. The following require a consideration of the operating and capital costs, as well as the consumptions and emissions, over the payback period of the investment:

- selection of which type of paint and application system
- the amount of automation
- the amount of waste gas treatment and paint system requires
- the operating life of the existing paintshop (see Section 2.2.1).

**Reference information:**
[127, TWG, , 152, EC, 2003, 159, EIPPCB, 2006, 166, DEFRA, 2003, 167, EIPPCB, 2006] [141, EU, 2007]

### 2.2.2 Systems management approach

**Description**
Work in the SAVE programme has shown that, while there are savings to be gained by optimising individual components (such as motors, pumps or heat exchangers, etc), the biggest energy efficiency gains are to be had by taking a systems approach, starting with the installation, considering the component units and systems and optimising (a) how these interact, and (b) optimising the system. Only then should any remaining devices be optimised.

This is important for utility systems. Historically, operators have tended to focus on improvements in energy-using processes and other equipment: demand-side energy management. However, the amount of energy used on a site can also be reduced by the way the energy is sourced and supplied: supply-side energy management (or utilities management), where there are options, see Section 2.7.5.

Sections 1.3.4 and 1.5.1 discuss how a top-down, systems approach can show how to achieve higher energy efficiency gains.

**Achieved environmental benefits**
Higher energy savings that achieved at a component level (bottom-up approach): For example: A new motor in a CAS or pumping system may save 2 % of the energy input: optimising the system may save 30 % or more (depending on the condition of system). It may also reduce waste and waste waters, process losses, etc.

### Cross-media effects
None.

### Operational data
Details are given in the relevant sections, such as:

- Section 2.7.5: Model-based utilities optimisation
- Chapter 3 deals predominantly with individual systems.

### Applicability
All installations.

### Economics
See relevant sections.

### Driving force for implementation
Cost. Increased efficiency. Reduced capital investment.

### Examples
See relevant sections

### Reference information
[168, PNEUROP, 2007, 169, EC, 1993, 170, EC, 2003, 171, de Smedt P. Petela E., 2006]

### 2.2.3 Energy efficient design

**Description**

The application of energy efficient design' (EED) has proved to be one of the most cost-efficient and attractive ways to improve energy efficiency in industry as well as in other major energy consuming sectors.

In the planning phase of a new plant or installation (or one undergoing major refurbishment), life-time energy costs of processes, equipment and utility systems should be assessed. Frequently, energy costs can then be seen to be the major part of the total costs of ownership (TCO), as illustrated for typical industrial equipment in figure 1 below.

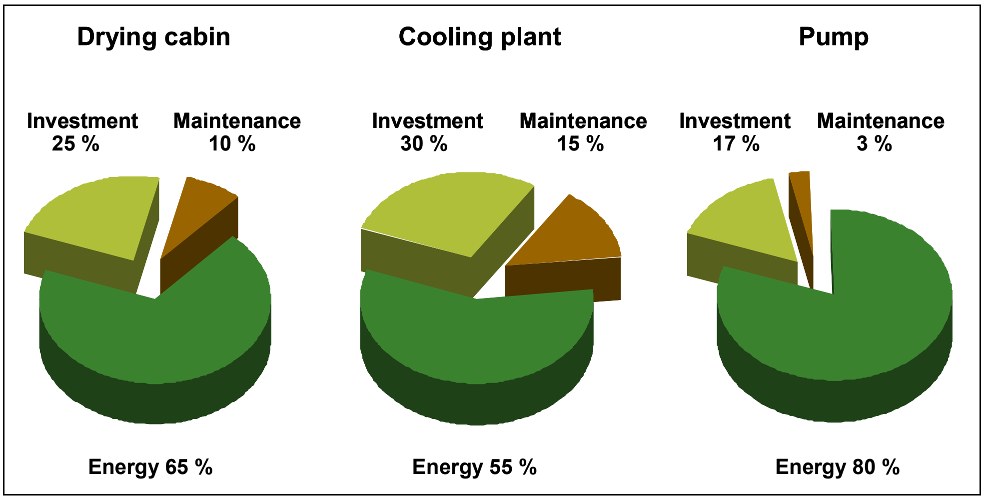


**Figure 2.2: Examples of total costs of ownership for typical industrial equipment (over 10 year lifetime)**

Experience shows that, if energy efficiency is considered during the planning and design phases of a new plant, saving potentials are higher and the necessary investments to achieve the savings are much lower, compared with optimising a plant in commercial operation. This is illustrated in Figure 2.3 below.

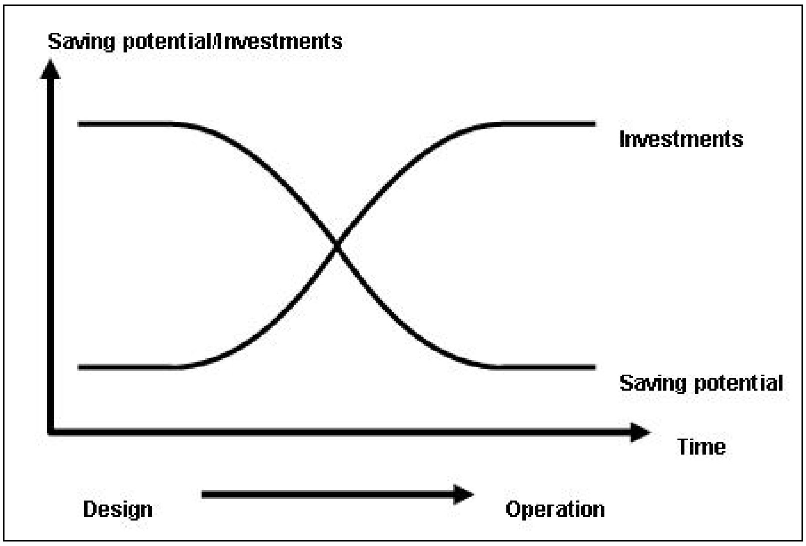


**Figure 2.3: Saving potentials and investments in design phase as compared to operational phase**

Energy efficient design uses the same technical knowledge and the same activities and methodologies as carrying out energy audits at existing sites. The major difference occurs because areas such as basic design parameters, selection of the process to be used (see Section 2.2.3.1) and major process equipment, etc., can be addressed in the design phase as illustrated in Figure 2.4 below. This allows the selection of the most energy-efficient technologies to be selected. These areas are often impossible or at least very expensive to address in a plant in commercial operation.

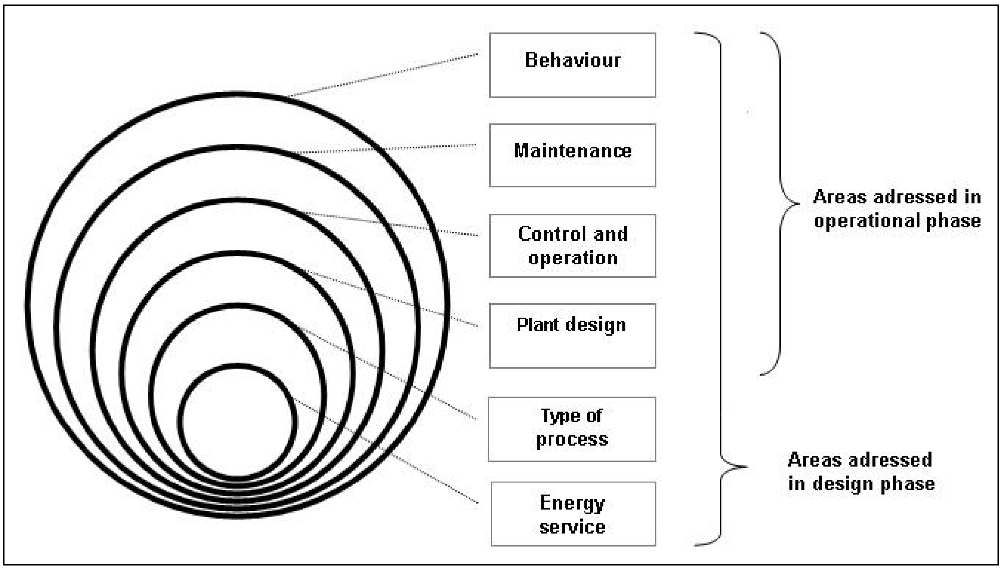


**Figure 2.4: Areas to be addressed in the design phase rather than the operational phase**

Typical examples of how energy services and the real need for energy can be addressed and analysed are the determination of:

- the airflow requirement in planned HVAC installations: what can be done to reduce the airflow in the central HVAC systems?
- the low temperature requirement of brine in a cooling system: which processes should be changed or optimised to reduce the cooling load and to raise the brine-temperature?
- the heat load in a drying process: which process parameters and plant principles can be changed in order to minimize the heat load? (see Section 3.9)
- the need for steam in a process plant? Could hot water be used so waste heat can be utilised for heating purposes? (see Section 3.2)
- the pressure need for compressed air: Can the pressure be reduced, or the system split into high and medium pressure systems? (see Section 3.7)

Pinch technology can be used to provide answers to some of these questions, where there are both hot and cold streams in a unit or installation (see Section 2.9).

Experience shows that the largest savings are achieved in new builds and significant upgrades; however this should not prevent the technique being applied to the planning and design of a retrofit, upgrade or major refurbishment.

These questions appear simple to answer, but a number of issues must be addressed to clarify saving potentials. Experience again shows that the planning and design process schedules are demanding and frequently run to tight schedules, often to a point where no time (or resource) is available for further analysis of saving potentials. Consequently, the work process of EED should closely follow the planning and design activities as illustrated for a typical construction process in Table 2.2 below.

| Construction phase | EED activity |
|---|---|
| Basic design/<br>Conceptual design | • enforced data collection regarding energy usage for new facility<br>• assessment of the real energy needs<br>• assessment of life-time energy costs<br>• review of basic design parameters influencing energy consumption<br>• identification of key persons and parties influencing energy efficiency for new facility<br>• minimisation of energy services<br>• introduction of best available technology |
| Detailed design | • design of optimal process plants and utility systems<br>• assessment of needs for control and instrumentation<br>• process Integration/heat recovery systems (Pinch methodology)<br>• minimisation of pressure losses, temperature losses etc.<br>• selection of efficient motors, drives, pumps etc.<br>• supplementary specifications to tendering material regarding energy efficiency |
| Tendering process | • ask tenders and manufactures for more energy efficient solutions<br>• quality control of plant designs and specifications in tenders |
| Construction and erection | • quality control of specifications for installed equipment as compared to equipment specified in tenders |
| Commissioning | • optimization of processes and utilities according to specifications |
| Operational phase | • energy audits<br>• energy management |

**Table 2.2: Example of activities during energy efficient design of a new industrial site**

The 'assessment of real energy needs' is fundamental to EED work and is central to identifying the most attractive areas to address during the later stages of the planning and design process. In theory, this sequence of activities can be used for both the design of complex process plants and in the procurement of simple machines and installations. Major investments being planned and budgeted for should be identified, for example, in a yearly management review, and the need for specific attention for energy efficiency identified.

### Achieved environmental benefits

The EED methodology targets the maximum energy saving potential in industry and enables application of energy efficient solutions that may not be feasible in retrofit studies. Implemented savings of 20 - 30 % of total energy consumption have been achieved in a large number of projects. Such savings are significantly more than achieved in energy audits for plants in operation.

### Cross-media effects

None.

### Operational data

Some examples of results from EED in different industrial sectors are shown in Table 2.3 below.

| Company | Savings (Euro/year) | Saving (%) | Investments (Euro) | Pay-back (years) |
|---|---|---|---|---|
| Food ingredients:<br>• new cooling concepts<br>• change of fermentation process<br>• reduced HVAC in packaging areas<br>• heat recovery from fermentor<br>• new lighting principles | 130 000 | 30 | 115 000 | 0.8 |
| Sweets:<br>• improved control of drying process<br>• optimise cooling circuit<br>• reduced infrared drying of products<br>• reduced compressed air pressure<br>• cheaper heat source (district heating) | 65 000 | 20 | 50 000 | 0.7 |
| Ready meals:<br>• change of heat source for ovens<br>• new freezing technology<br>• new heat recovery concept<br>• optimized $NH_3$-cooling-plant<br>• optimized heat exchangers | 740 000 | 30 | 1 500 000 | 2.1 |
| Plastics:<br>• new cooling concept (natural cooling)<br>• heat recovery for building heating<br>• reduced pressure compressed air<br>• reduced HVAC systems | 130 000 | 20 | 410 000 | 3.2 |
| Abattoir:<br>• comprehensive heat recovery<br>• optimised cleaning processes<br>• reduced freezing and cooling load<br>• improved control of cooling processes<br>• use of tallow for heating premises | 2 000 000 | 30 | 5 000 000 | 2.5 |

**Table 2.3: Achieved savings and investments in five pilot projects for EED**

Compared to traditional energy audits, the total socio-economic cost-benefit ratio for the implemented savings from EED are 3 - 4 times higher.

It is recommended the EED work is carried out in a number of project phases, for example:

1. Assessment of energy consumption data and focus areas
2. Minimization of energy service and application of BAT
3. Provision of input for plant design, control and instrumentation
4. Quality assurance of tenders
5. Follow-up.

Each project phase should deliver specific outputs so that the operator can decide which further investigations that should be carried out.

In order to achieve the best possible result of the EDD work, the following criteria are important:

- even though the planned investments are not well defined in the early stages of the conceptual design/basic design phase, the EED should be initiated at this stage to achieve maximum savings and not to delay the design process
- in the early stage of the conceptual design/basic design phase, data for energy consumption is not available. It is very important that all energy consumption data are assessed by the person responsible for the EED. Most often, suppliers and manufacturers cannot (or will not) supply data at this stage and life-time costs must be assessed by other means. Data collection may need to be carried out, as part of the design project or separately
- the EED work should be carried out by an energy expert independent from the design organisation as illustrated in figure 3 below:

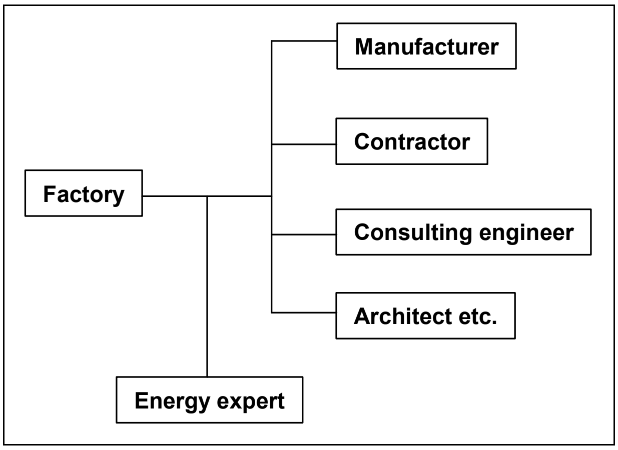


**Figure 2.5: Recommended organisation including an energy expert in the planning and design of new facilities**

- in addition to end-use consumption, the initial mapping of energy consumption should also address which parties in the project organisations influence the future energy consumption. As an example, the staff in the (existing) factory are often responsible for specification of the most important design parameter(s) to optimise a reduction of the energy efficiency of the future plant
- a risk assessment of tenders and other data should clarify which manufactures will not benefit from optimising energy efficiency of their delivered products for the project. For example, strong price competition often necessitates that manufactures of plant use cheap components, minimise heat exchangers etc. which will result in increased life-time operating costs of the plant.

It is important to stress that the EED work is often multi-disciplinary and that the independent energy expert should not only be technically capable but should have significant experience in working with complex organisations and with complex technical problems.

**Applicability**
EED has been applied successfully in most industrial sectors and savings have been introduced at installation level, in process units and utility systems.

An important barrier against success is that manufactures are often conservative or unwilling to change a well-proven standard design and/or to update product guarantees, etc.

It is important that the EED work is initiated in the early stages of the conceptual design work and is organised well in order to avoid time delays in the planning and design process.

Even though EED basically will focus on well-known technologies and principles, new technology or more complex solutions are often introduced. This must be considered as a risk seen from the client's perspective.

### Economics

The fee for the independent energy expert may be of the magnitude 0.2 to 1 % of the planned investment, depending on the magnitude and character of the energy consumption.

In many cases, in addition to energy savings, the EED process results in lower investments, as fundamental energy services can be minimised (such as cooling, heating, CAS, etc.).

It has been demonstrated that a well-designed process plant often has a higher capacity than a traditionally designed plant as key equipment, such as heat exchangers etc. have more capacity in order to minimise energy losses.

### Driving force for implementation

The primary drivers for EED are:

- lower operational costs
- application of new technology (an opportunity to implement BAT)
- well-designed plants due to better design practice and data.

There may also be benefits in increased throughput, reduced waste, improved product quality (see Section 2.2.3.1).

### Examples

A number (10) of official Danish pilot projects have been reported, for example:

- a new abattoir at Danish Crown, Horsens, Denmark (www.danishcrown.com)
- a new ready meal factory at Danpo, Farre, Denmark (www.danpo.dk)
- a new ingredients plant at Chr. Hansen, Avedøre Holme, Denmark (www.chrhansen.com)
- a new potato starch plant, Karup Kartoffelmelfabrik, Denmark (an EU LIFE project).

Official reports (in Danish) on these projects are available at the Danish Energy Agency (www.ens.dk).

Animal housing design is included in the BAT for energy efficiency in the intensive livestock farming of pigs and chickens [173, EIPPCB, 2003].

### Reference information

The Organisation of Consulting Engineers (F.R.I) has carried out a comprehensive study to develop methodologies and guidelines in the area of energy efficient design. This material (in Danish) can be ordered from www.frinet.dk.

The Danish Agreements Scheme has described a number of cases as well as methodologies to be followed by major energy consuming industries (in Danish), see www.end.dk.

ILF BREF 2003, Sections 5.2.4 and Section 5.3.4.
[174, EC, 2007]

### 2.2.3.1 Selection of process technology

**Description**

This is a key part of energy efficiency design which merits highlighting, as the selection of a process technology can usually only be considered for a new build or major upgrade. In many cases, this may be the only opportunity to implement the most effective energy saving options. It is good practice to consider technological developments in the process concerned (see Section 2.1(k)).

There may be more than one process step using different technologies. One or more processes may be changed when upgrading, e.g. intermediates may be created which are then subsequently processed further.

Examples are:

- the use of catalysis in chemical reactions. Catalysts lower the activation energy and, depending on the reaction, may reduce the heat energy input required. Catalysts have been used for many years, but research is still active in all types. Currently, there is major interest in biotechnological approaches (such as biocatalysis), and its role in the production of organic chemicals, pharmaceuticals, biofuels, etc.
- use of radiation cured ink or paint systems in place of conventional solvent based systems
- the use of heat recovery with under floor heating systems for housing livestock farming.

**Achieved environmental benefits**

Dependent on the process: changing the process can deliver significant energy savings, and may also reduce wastes and/or decrease the hazardous content, reduce other emissions such as solvents, etc. See Examples.

**Cross-media effects**

Dependent on the process. See Examples.

**Operational data**

Dependent on the process. See Examples.

**Applicability**

Dependent on the installation. See Examples.

**Economics**

Dependent on the process. See Examples.

**Driving force for implementation**

Dependent on the process: this may include cost reduction, higher yields, higher product quality (e.g. stereospecificity), less by-products, lower toxicity of wastes, etc.

For catalysts:

- the need for selectivity of products in some cases
- some reactions cannot occur without a catalyst (although a reaction may be feasible from thermodynamic calculations).

**Examples**

See Annex 4

1. The enzymatic production of acrylamide (Mitsubishi Rayon, Japan).
2. Use of radiation cured inks or paint systems in place of conventional solvent based systems
3. Heat recovery in broiler housing (intensive chicken farming)

**Reference information**

[164, OECD, 2001, 175, Saunders_R., 2006]
Broiler housing: Section 4.4.1.4, [173, EIPPCB, 2003]

### 2.2.4 Increased process integration

**Description**

Optimising the use of raw materials and energy between more than one process or system. This is site- and process-specific, but can be illustrated with an example:

In the example plant (see the LVIC-AAF BREF, Section 1.4.1), the integration of the nitric acid and AN plants has been increased (AN: Ammonium Nitrate ($NH_4NO_3$)). The following measures have been realised:

- gaseous (superheated) $NH_3$ is a common raw material, both plants can share one $NH_3$ vapouriser, operated with process steam from the AN plant
- LP steam available in the AN plant can be used to heat the boiler feed-water (BFW) from 43ºC to about 100 ºC through two heat exchangers
- the hot BFW can then also be used to preheat the tail gas of the nitric acid plant
- process condensate from the AN plant is recycled to the absorption column of the nitric acid plant.

**Achieved environmental benefits**

- improved energy efficiency
- reduced emissions to water
- savings in demineralised water.

**Cross-media effects**

None believed to be likely.

**Operational data**

No information provided.

**Applicability**

Generally applicable. Especially applicable where processes are interdependent anyway. However, the options for improvement will depend on the particular case.

On an integrated site, it has to be considered that changes in one plant might affect the operating parameters of other plants. This applies also to changes with environmental driving forces [154, TWG on LVIC-AAF, 2006].

- improved energy efficiency
- less consumption of demineralised water
- lower investment by using a common ammonia vaporiser.

In the example, savings in operation costs of more than EUR 1000 000/year are achieved.

**Driving force for implementation**
Cost benefits and reduced emissions to water.

**Economics**
Cost benefits through:

**Examples**
Grande Paroisse, Rouen, FR.
New potato starch plant, Karup Kartoffelmelfabrik, Denmark (an EU LIFE project)

**Reference information**
[174, EC, 2007, 221, EIPPCB]

### 2.2.5 Maintaining the impetus of energy efficiency initiatives

**Description**
Several problems with maintaining the impetus and delivery of energy efficiency programmes have been identified. There is a need to see whether savings in energy efficiency due to adoption of a new technology or technique are sustained over time. No account is taken of 'slippage' through inefficient operation or maintenance of equipment, etc.

Problems identified include (some of the techniques to overcome these problems are described in other sections, see below):

- the evolution of strategies can be seen in terms of a life cycle, where strategies mature. They need to be reviewed (approximately every two years) to ensure they remain appropriate in terms of the target audience and the intervention method
- there is a need for maintenance activity within the strategy to ensure the appropriateness of content of communications, by updating information and monitoring the impact. This can include the use of interactive methods of communication, etc.
- sustaining E2 savings and the maintenance of good practice to the extent of embedding it in the culture (of an installation)
- ‘staleness’ from a management perspective affects the enthusiasm with which dissemination occurs (see also Maintaining expertise, Section 2.3)
- training and continuing development at all staff levels (see also Maintaining expertise, Section 2.3)
- technological developments (see Sections 2.2.1, 2.2.2, 2.2.3, etc).

Techniques that may add impetus to energy efficiency programmes are:

- implementing a specific energy efficiency management system (see Section 2.1)
- accounting for energy usage based on real (metered) values and not estimates or fixed parts of whole site usage. This places both the onus and credit for energy efficiency on the user/bill payer (see Sections 2.7.2 and 2.7.5)
- a fresh look at existing systems, such as using Operational Excellence (described below)
- using change management techniques (also a feature of Operational Excellence). It is a natural human trait to resist change unless a benefit can be shown to the person implementing the change. Calculating the benefits of options (on-line or off-line, e.g. what-if scenarios) that can be demonstrated to be reliable, and communicating them effectively can contribute to motivating the necessary change(s) (For an example of data provision, see Section 2.7.5).

Operational Excellence (also known as OpX), is a holistic approach to the systematic management of safety, health, environment, reliability and efficiency. It integrates operations management methodologies such as Lean Manufacturing & Six Sigma with change management to optimise how people, the equipment and processes function together. It is associated with statements such as 'the state or condition of superiority in operations and execution of business processes', and 'to achieve world-class performance'.

It is the continual refinement of critical operation processes, and focuses on reducing waste and cycle time through a mixture of techniques, such as 5-S, Error-proofing, QFD, SPD, etc.

The steps taken are those identified in E2 management systems (see Section 2.1), with an emphasis on:

- determining best practice (the goals that operations teams are striving for in performing a particular process at a level of excellence)
- detailed descriptions of each operational best practice (including changes and improvements)
- identifying the metrics required measure operations performance levels
- the key skills operational personnel must have to be able to perform the process.

Key features are making use of in-house expertise, including that from other units (or associated companies), forming ad hoc teams to identify best working practices, work with staff in other non-optimised units, etc.

### Achieved environmental benefits

Operational Excellence: Maintained or improved impetus to energy efficiency programmes.
As it is holistic, it also improves the application of other environmental measures.

### Cross-media effects

None.

### Operational data

See Description and Examples

### Applicability

The principles of E2MS and Operational Excellence are widely applicable.

### Economics

See Examples. For E2MS, see Section 2.1.
For Operational Excellence, low capital investment, realising significant returns.

### Driving force for implementation

Cost saving. As it is holistic, it also improves the application of other production control measures, resulting in reduced waste, and reduced cycle times, etc.

**Examples**
Examples for E2MS are given in Annex 3
Examples of the application of Operational Excellence are given in Annex 5

1. Shell Nederland Chemie, Moerdijk, the Netherlands (900,000 mt/year ethylene plant).
Energy savings of USD 5 million/year (about EUR 3.6 million), or 3.5 % were achieved.

2. Dow Corning, several installations. Hidden capacity in all plants of generally 15 - 20 % was revealed, with minimal capital investment.

**Reference information**
[176, Boden_M., 2007, 177, Beacock, 2007]

## 2.3 Maintaining expertise – human resources

**Description**
This factor is identified in Sections 2.1(i) and (ii). The levels of skilled staff in virtually all European installations have been reduced over recent decades. Existing staff may be required to multi-task and cover a range of tasks and equipment. While this may cover normal operations and retain expertise in some areas, over time it may reduce specialist knowledge of individual systems (e.g. CAS) or specialities, such as energy management, and reduce the staff resource to carry out non-routine work, such as energy audits and follow-up investigations.

Training activity has been identified as an important factor in implementing energy efficiency programmes and embedding energy efficiency in the organisational culture and includes:

- higher and professional education curricula
- training opportunities associated with specific skills and vocational areas, and ad hoc training possibilities across professional, managerial, administrative and technical areas
- continuing development in the energy management area: all managerial staff should have awareness of energy efficiency, not just co-opted energy managers.

“Staleness” from a management perspective also influences the enthusiasm with which energy efficiency dissemination occurs and human resource mechanisms can achieve positive changes. These might include rotation, secondments, further training, etc.

In order to deliver energy savings, operators may need additional resources in both staff numbers and skills.

This can be achieved through one or more of several options, such as:

- recruitment and/or training of permanent staff
- taking staff off-line periodically to perform fixed term/specific investigations (in their original installation or in others, see Section 2.2.5)
- sharing in-house resources between sites (see Section 2.2.5)
- use of appropriately skilled consultants for fixed term investigations
- outsourcing specialist systems and/or functions (see Section 5.1.10).

Training can be delivered by in-house staff, by external experts or by formal courses.

A training course leading to the qualification of EUREM (European Energy Manager (Production) is a project realised in the framework of the SAVE programme, and after a successful pilot project, the project has been extended.

### Achieved environmental benefits

Enables the delivery of energy efficiency.

### Cross-media effects

None.

### Operational data

### Applicability

At all sites, see Operational data, above. It is worth noting that even sites achieving high levels of energy efficiency have benefited from additional resource (see Operational Excellence, Section 2.2.5.

### Economics

Cost of additional staff or consultants. Some MS have energy saving initiatives where independent energy efficiency advice and/or investigations are subsidised (see Chapter 5).

See EUREM, in Examples, below.

### Driving force for implementation

Unrealised cost savings, even in efficient organisations.

### Examples

Many examples quoted where outside experts are brought in to supplement internal resources, see Reference information.
NL hospital, Honeywell.

The EUREM pilot project trained 54 participants in four countries (DE, AT, UK, PT).The course comprises about 140 hours of lessons, plus about 60 hours of self-study via the internet and for a feasibility study. In Germany (Nuremberg) the course is run as 6 months' lessons (Fridays and Saturdays every 2 or 3 weeks), and 3 to 4 months project work. Costs depend on the country and facilities available: about EUR 2100 in Germany and EUR 2300 in Austria (2005-6).

| | **Plan** | **Actual** |
|---|---|---|
| Energy savings per participant | 400 MWh/year | 1280 MWh/year |
| Cost savings per participant | 16 000 EUR/yr | 73 286 EUR/yr |
| Average payback period (on investment required) | - | 3.8 years |
| Average payback (of direct cost of course, based on 230 work days/yr) | | 33 times training cost (7 working days) |

**Table 2.4: EUREM pilot project: savings per participant**

### Reference information

[176, Boden_M., 2007]
[188, Carbon_Trust_(UK), 2005]
[161, SEI, 2006, 179, Stijns, 2005]
[180, Ankirchner, 2007]

## 2.4 Communication and employee involvement

*TWG: These are key issues which can be identified in many of the examples used. However, they have not been discussed, as (a) it is likely to be difficult to identify in a permit, (b) no clear techniques have been identified.*

## 2.5 Effective process control

**Description**

When product is scrapped or reworked, the energy used in the original production process is wasted (as well as raw materials, labour and production capacity and other resources). Reworking may use disproportionately more energy (and other resources) than the original production process. Effective process control increases the amount of product(s) meeting production/customers' specifications and reduces the amount of energy wasted.

IPPC installations usually involve large scale production and/or high volumes of throughput. Usually the products have to meet specifications for subsequent use. Quality assurance systems (QA) have been developed to ensure this, which is usually based on the PDCS (plan-do-check-act) approach (see Section 2.1)

Originally this was based on testing products, and accepting or rejecting, reworking and scrapping products that have already been through the whole production process. Statistical methods were developed (during the 1940's onwards) to set sampling and testing on a statistical basis to ensure a certain level of compliance with standards, e.g. 95 %.

It was realised that a manufactured product has variation and this variation is affected by various process parameters. Statistical Process Control (SPC) was developed, and applied to control each parameter, and the final result tends to be a more controlled product. SPC can be very cost efficient, as it usually requires collection and charting data already available, assessing deviation of the process, and applying corrective action to maintain the process within predetermined control parameters (such as temperature, pressure, chemical concentration, colour, etc).

At the same time, company-wide quality approaches were developed (quality management systems, QMS). These can be defined as a set of policies, processes and procedures required for planning and execution (production /development /service) in their core business area of an organization. QMS integrates the various internal processes within the organization and intends to provide a process approach for project execution. QMS enables the organizations to identify, measure, control and improve the various core business processes that will ultimately lead to improved business performance. The models for quality assurance are now defined by the international standards contained in the ISO 9000 series and the specified specifications for quality systems. Environmental management and energy management systems have been developed from the same systems approaches (see Section 2.1).

More recent developments include:

- Right First Time
- Six Sigma: where the likelihood of an unexpected failure is confined to six standard deviations (where sigma is the standard deviation and equates to 3.4 defects per million)
- Measurement Systems Analysis (MSA)
- Failure Mode and Effects Analysis (FMEA)
- Advance Product Quality Planning (APQP)
- Total Quality Management (TQM).

Another approach (which may be combined with the above) are quality circles. These are small groups of employees from the same work area who voluntarily meet at regular intervals to identify, analyse, and resolve work related problems. Quality circles have the advantage of continuity; the circle remains intact from project to project. These are used in Japan and innovative companies in Scandinavian countries.

Process Control Engineering (Prozessleittechnik, Bayer AG, 1980) was developed as a working title covering the measurement, control, and electrical engineering groups. It is a statistics and engineering discipline that deals with architectures, mechanisms, and algorithms for controlling the output of a specific process.

### Achieved environmental benefits

Reduction in rejects and/or reworking which is a waste of the original energy input, and may require greater energy input for reworking (or decreased output from the batch).

### Cross-media effects

None.

### Operational data

See Description, above.

Consultants and/or contractors are often used when introducing new quality practices and methodologies as, in some instances, the relevant skill-set and experience might not be available within the organisation. In addition, when new initiatives and improvements are required to bolster the current quality system, or perhaps improve upon current manufacturing systems, the use of temporary consultants is an option when allocating resources.

### Applicability

A criticism of statistical methods such as Six Sigma is that they are effective at what it is intended, but are narrowly designed to fix an existing process and do not help in developing new products or disruptive technologies. The Six Sigma definition is also based on arbitrary standards. While 3.4 defects per million might work well for certain products/processes, it might not be ideal for others.

The following arguments have been made for and against management systems:

- the application of these approaches gain popularity in management circles then lose it, with a life cycle in the form of a Gaussian distribution
- the term TQM created a positive utility, regardless of what managers meant by it, however, it lost this positive aspect and sometimes gained negative associations.

Despite this, management concepts such as TQM and Re-engineering leave their traces, without explicit use of their names, as the core ideas can be valuable.

The loss of interest/perceived failure of such systems could be because systems such as ISO 9000 promote specification, control, and procedures rather than understanding and improvement, and can mislead companies into thinking certification means better quality. This may undermine the need for an organisation to set its own quality standards. Total, blind reliance on the specifications of ISO 9000 does not guarantee a successful quality system. The standard may be more prone to failure when a company is interested in certification before quality. This creates the risk of creating a paper system that does not influence the organisation for the better.

Certification by an independent auditor is often seen as a problem area and has been criticised as a vehicle to increase consulting services. ISO itself advises that ISO 9000 can be implemented without certification, simply for the quality benefits that can be achieved.

### Economics

A common criticism of formal systems such as ISO 9000 is the amount of money, time and paperwork required for registration. Opponents claim that it is only for documentation. Proponents believe that if a company has documented its quality systems, then most of the paperwork has already been completed.

### Driving force for implementation

Proper quality management has been widely acknowledged to improve business, often having a positive effect on investment, market share, sales growth, sales margins, competitive advantage, and avoidance of litigation.

### Examples

See Annex 3.

### Reference information

[163, Dow, 2005, 181, Wikipedia, , 182, Wikipedia]

## 2.6 Maintenance

**Description**
Maintenance of all plants and equipment is essential and forms part of an E2MS (see Section 2.1(d) (vii).

It is important to keep a maintenance schedule and record of all inspections and maintenance activities. Maintenance activities are given in the individual sections.

The preventative maintenance programme may be organised and supported by computer software. By flagging-up planned maintenance on a daily basis until it is completed, preventative maintenance software can help to ensure that no maintenance jobs are forgotten.

Process operators should carry out local actions and help to focus unscheduled maintenance such as:

- identifying and reporting leaks, broken equipment, fractured pipes, etc.
- requesting timely replacement of worn bearings
- ensuring that adjustable equipment is optimised (e.g. in printing presses)
- switching off equipment when not in use or not needed.

**Achieved environmental benefits**
Energy savings. Reduction in noise (e.g. from worn bearings, escaping steam).

**Cross-media effects**
None.

**Operational data**
Installation dependent.

**Applicability**
Generally applied.

**Economics**
Installation dependent.

**Driving forces for implementation**
Generally accepted to increase plant reliability, reduce breakdowntime, increase throughput, assist with higher quality.

**Examples**
Widely applied in all sectors.

**Reference information**
Several BREFs.

## 2.7 Monitoring and measurement

[55, Best practice programme, 1998][56, Best practice programme, 1996] [98, Sitny, 2006].

Monitoring and measurement are an essential part of checking in a ‘plan-do-check-act’ system, such as in E2MS (Section 2.1(f)(i)). This section discusses possible techniques to measure, calculate and monitor key characteristics of operation and activities that can have a significant impact on energy efficiency. It also discusses the automation of the control systems and equipment, particularly several interconnected systems, to optimise their use of energy.

Measurement and monitoring are likely to form part of process control (see Section 2.5) as well as auditing (see Section 2.8). Measurement is important to be able to acquire reliable and traceable information on the issues which influence energy efficiency, both in terms of its amounts (MWh, kg steam, etc.) but also its qualities (temperature, pressure, etc), according to the vector. For some vectors (steam, hot water, cooling, etc), it may be equally important to know the parameters of the energy vector in the return circuits or waste discharges (e.g. waste gases, cooling water discharges) to enable energy analyses and balances to be made, etc. (see examples, Section 2.9).

A key aspect of monitoring and measurement is to enable cost accounting to be based on real energy consumptions, and not on arbitrary or estimated values (which may be out of date). This provides impetus to changes to improve energy efficiency.

This section does not discuss documentation or other procedures required by any energy efficiency management system.

In additional, material flows are often measured for process control, and these data can be used to establish energy efficiency indicators, etc (see Section 1.4)

### 2.7.1 Qualitative techniques

**Description**
Infrared scanning of heavy machinery provides photographic proof of hot spots that cause energy drains and unnecessary stress on moving parts. This may be used as part of an audit.

Critical bearings, capacitors (see Section 3.5.1) and other equipment may have the operating temperature monitored continuously or at regular intervals: when the bearing or capacitance starts to breakdown, the temperature of the casing rises.

Other measurements can be made of other energy losses, such as noise, etc.

**Achieved environmental benefits**
Energy saving.

**Cross-media effects**
None.

**Operational data**
See Description, above.

**Applicability**
Widely used.

### Economics

Case dependent.

### Driving force for implementation

As part of preventative maintenance:

- avoids unexpected plant shutdown
- enables planned replacement
- extends life of equipment, etc.

### Examples

Aughinish Alumina (AAL), Ireland
See Sections 3.2, 3.7, etc.

### Reference information

[161, SEI, 2006, 183, Bovankovich, 2007]

## 2.7.2 Quantitative measurements – metering and advanced metering systems

### Description

Utility meters are used to generate energy bills for industrial installations. However, modern technological advances result in cheaper meters, which can be installed without interrupting the energy supply (when installed with split-core current sensors) and require far less space than older meters.

Where there is more than one energy-using system or unit in an installation, advanced meters can be installed at the various units and systems. Energy account centres are the units at the site where energy usage can be related to a production variable such as throughput (see Section 1.4). An example of a structure of an advanced metering system is shown in Figure 2.6.

An advanced metering system is essential to automated energy management systems, see Sections 2.7.4 and 2.7.5.

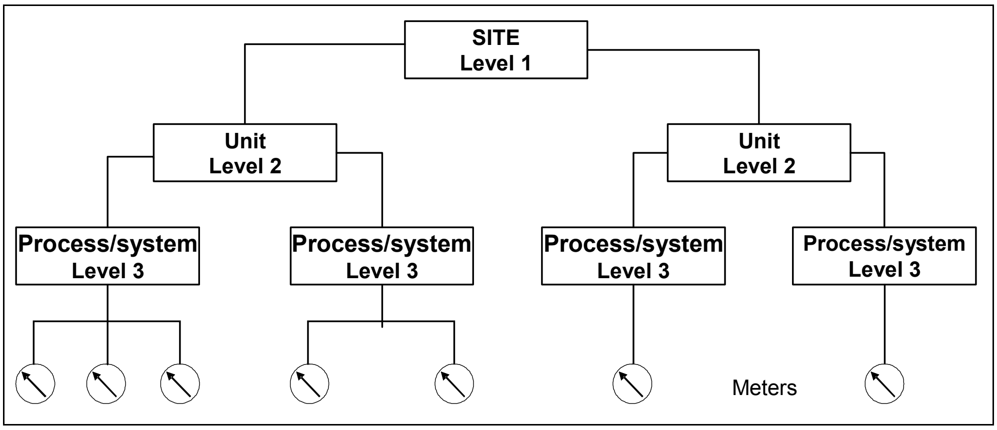


**Figure 2.6: Structure of an advanced metering system**
**[98, Sitny, 2006]**

### Achieved environmental benefits

Better control of energy usage.

### Cross-media effects

None.

### Operational data

Enables accurate measurement energy usage to energy account centres, within an installation, with specific units and systems.

### Applicability

Where there are more than one system of unit using energy.

Several studies show a major reason for energy efficiency techniques not being implemented is that individual unit managers are not being able to identify and control their own energy costs. They therefore do not benefit from any actions they implement.

### Economics

Allocation of costs on a usage basis.

### Driving force for implementation

See Economics.

### Examples

See Annex 6

### Reference information

[183, Bovankovich, 2007]

## 2.7.3 Flow measurement in fluids – new generation devices

### Description

Flow measurement is used in fluids such as liquid and gaseous raw materials and products, water (raw water, boiler and process waters, etc), steam, etc. They are usually measured by an artificially induced pressure drop across an orifice plate, a venturi or pitot tube, or by an inductive flow-meter. Traditionally, this results in a permanent pressure drop, particularly for orifice plates and venturi i.e. loss in energy in the system. These two devices also have relatively high inaccuracies, normally accepted by operators at about 2 - 3 % of the scale end value. Also, the remaining pressure drop in the gas or steam creates an influence which results in considerable inaccuracies in large-scale measurements.

A new generation of flow measurement devices reduce the pressure losses significantly, with increased accuracy.

### Achieved environmental benefits

New generation flow-meters and pitot tubes have very high accuracy (less than +/-0.5 % deviation of every measured value), with 1 - 2 % of the energy loss of a traditional orifice plate, and 8 % of a traditional pitot tube.

### Cross-media effects

None.

## Operational data

| Base data | Power station with high-pressure steam | Waste incineration with super - heated steam |
|---|---|---|
| Q max (t/h) | 200 | 45 |
| T (°C) | 545 | 400 |
| P (barabs) | 255 | 40 |
| pipe ID (mm) | 157 | 130.7 |
| | | |
| **Differential pressures in mbar at about:** | | |
| orifice plates | 2580 | 1850 |
| pitot tubes hitherto | 1770 | 595 |
| pitot tubes new generation | 1288 | 444 |
| | | |
| **Permanent pressure drop in mbar and per measuring system in mbar at about:** | | |
| orifice plates | 993 | 914 |
| pitot tubes hitherto | 237 | 99 |
| pitot tubes new generation | 19.3 | 7.3 |
| | | |
| **Kinematic energy loss per measuring system in kWh/h (with 100 mbar ≈ 67.8 kWh/h) at about:** | | |
| orifice plate | 673 | 620 |
| pitot tubes hitherto | 161 | 67 |
| pitot tubes new generation | 13 | 5 |

**Table 2.5: Examples of pressure drop caused by different metering systems**

## Applicability

The energy savings do not apply if the measurement device is deployed upstream of a regulated multi-stage steam turbine.

## Economics

Cost a new generation measuring device, including installation is about EUR 10 000. This may vary with numbers installed. Return on investment (RIO) is usually less than one year.

## Driving force for implementation

Cost savings. Data accuracy for process control (see Section 2.2.5)

## Examples

See Operation Data, above.

## Reference information

## 2.7.4 Energy models, databases and balances

**Description**

Energy models, or databases and balances, are useful tools to carry out a complete and in-depth energy analysis and are likely to be part of an analytical or comprehensive energy audit (see Section 2.8). A model is a plan or description designed to show where and how energy is used in an installation, unit or system (a database). The model therefore seeks to record the technical information about an installation, unit or system. It will record the type of equipment, energy consumption and operating data such as running time. It should be complete enough for the task (but not excessively so), easily accessible to various users in departments such as operations, energy management, maintenance, purchasing, accounts, etc. It may usefully be part of, or linked to a maintenance system, to facilitate record updating, such as motor rewinding, calibration dates, etc. (see Section 2.6).

An energy model can be built up based on system boundaries, and the auditor (or data gatherer) must take care to ensure the efficiency recorded is the real efficiency (see Section 1.5), e.g.:

- units (department, production line, etc)
  - system
    - individual equipment (pumps, motors, etc)
- utility systems (e.g. compressed air, pumping, vacuum, external lighting, etc)
  - individual equipment (pumps, motors, etc).

As an energy model is a strategic tool to carry out an energy audit, it is good practice to validate it before use by performing a balance. The first step is to compare the total amount of energy consumed, as derived from calculations, with the amount consumed as shown by the metered energy supplies. Where the installation is complex, this can be carried out at a unit or system level (see system boundaries, Section 1.5 and metering, Section 2.7.2). If the balance between the calculated and the metered consumptions is not achieved, then the data in the model should be rechecked, in particular any estimations, such as load factors and working hours. Where necessary, these should be established with greater accuracy. Another cause of errors is not identifying all the equipment using energy.

**Achieved environmental benefits**

Enables planning on the basis of knowing where energy is consumed.

**Cross-media effects**

None.

**Operational data**

Electrical energy

For an electric model, the following data can be gathered for each electrically powered device, such as motors and drives, pumps, compressors, electric furnaces, etc.

- rated power
- rated efficiency
- load factor
- working hours per year.

Whereas power and efficiency are easy to detect as they are normally labelled on the device itself, the load factor and the hours per year are estimated.

Examples of data gathered for a simple electrical energy model are given in Annex 6

When the load factor is estimated to be greater than 50 %, then the load factor itself is approximately equal to:

$$LF = \frac{P_{(eff)} \times \eta}{P_{(rated)}}$$

where:

- LF is the load factor
- $P_{(eff)}$ is the estimated average electric power effectively absorbed by the device during its working hours (kW)
- $P_{(rated)}$ is the rated power (kW)
- $\eta$ is the rated efficiency of the device (at full load).

If necessary $P_{eff}$ can be measured using electric power meters.

It must be pointed out that the efficiency and the power factor of a device depend on the load factor according to Figure 3.10, drawn in this case for a generic motor:

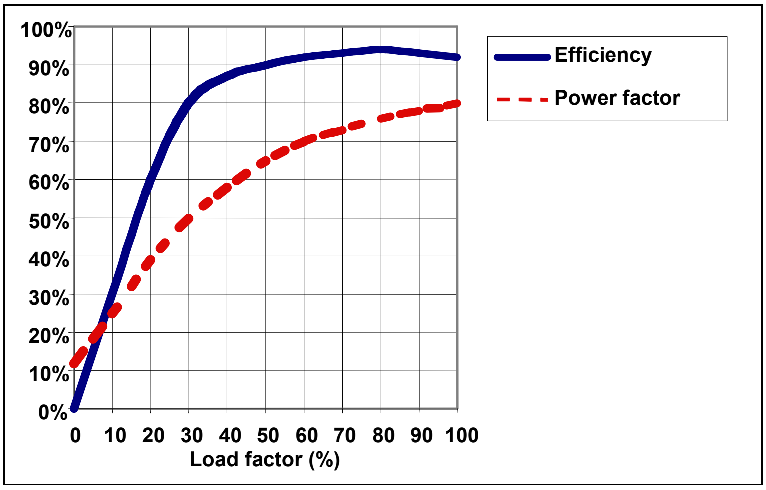


**Figure 2.7:Power factor of a device depending on the load factor**
**[11, Franco, 2005]**

### Thermal energy

The drawing up of a thermal energy model is more complex than an electric model. To have a complete picture of the thermal consumption, two kinds of models are compiled: first level and second level.

To compile the first level energy model, it is necessary to take a census of all users of any kind of fuel. For any consumer of fuel (e.g. boilers, furnaces), the following data should be recorded:

- type of fuel supplied in time period, usually in a year
- kind of thermal carrier entering the boiler (e.g. pressurised water): flowrate, temperature, pressure
- condensate: percentage of recovery, temperature, pressure
- boiler body: manufacturer, model, installation year, thermal power, rated efficiency, exchange surface area, number of working hours in a year, body temperature, average load factor
- burner: manufacturer, model, installation year, thermal power
- exhaust: flowrate, temperature, average carbon dioxide content
- kind of thermal carrier leaving the boiler (e.g. steam): temperature, pressure.

Though all such data should be collected, in the first level thermal model ('generators' side') only the major users of energy need to be taken into account (see Annex 6, Table 8.9). It is generally helpful to convert all energies into primary energy or specific energy types used in the industry, for later comparisons (see Section 1.3.5.1)

Second level models ('users' side') are also made by taking a census of all machineries needing thermal energy in any form (hot water, steam, hot air, etc.) except fuel (taken into account in the first level model). For every item of equipment using thermal energy, the following data should be collected:

- type of thermal carrier used
- hours/year of thermal demand
- load factor at which thermal energy is used
- rated thermal power.

An example of how data can be arranged is given in Annex 6, Table 8.9.

The second level model ('users' side') is useful to verify the match between the heat supplied by the utilities (boilers, heat generators, etc…) and the heat requested by the users.

If this difference is acceptable, then the two models can be considered as validated. If this is not the case, then some re-calculation or further investigation is needed.

If the difference between the two amounts is large, this is likely to be due to a high level of losses in the production-distribution-use for different carriers (e.g. steam, hot water, etc.). In this case, actions to improve the energy efficiencies should be taken.

### Applicability

The type of model and the detail of information gathered depend on the installation.
An analysis of every piece of energy consuming equipment is often not feasible or necessary. Electrical energy models are suitable for smaller installations. Process analysis including detailed electrical and thermal power consumption is more appropriate in larger installations.

### Economics

Site dependent.

### Driving force for implementation

Cost saving.

### Examples

Examples of energy data sheets and balance calculations are given in Annex 6.

### Reference information

[127, TWG][11, Franco, 2005]

## 2.7.5 Model-based utilities optimisation and management

### Description

This brings together techniques such as those described in Sections 2.7.2 to 2.7.4 and adds software modelling and/or control systems.

For simple installations, the availability of cheaper and easier monitoring, electronic data capture and control, make it easier for operators to gather data, assess process energy needs, and to control processes. This can start with simple timing, on-off switching, temperature and pressure controls, data loggers, etc. and is facilitated by using software models for more sophisticated control.

At the more complex levels, a large installation will have an information management system (manufacturing and execution systems), logging and controlling all the process conditions.

A specific application is in managing the way energy is sourced and supplied (supply-side energy management (or utilities management), see Applicability, below. This uses a software model linked to control systems to optimise and management the energy utilities (electricity, steam, cooling, etc).

### Achieved environmental benefits

Reduction in energy use and associated emissions. See Examples, below.

### Cross-media effects

Usually efficiencies are additive, but in some cases, if the supply side is not considered, then the benefits in reducing demand are not realised, e.g. when steam savings in one process unit simply lead to venting elsewhere if the steam system is not rebalanced.

### Operational data

With increasing complexity, optimum and energy efficient operation can be achieved by using the right tools, ranging from simple spreadsheet based simulation tools, or distributed control system (DCS) programming to more powerful model-based utilities management and optimisation system (a utilities optimiser) which might be integrated with other manufacturing and execution systems on site.

A utilities optimisation system will be accessed by staff with a variety of backgrounds and objectives (e.g. engineers, operators, plant managers, buyers, accounts staff). The following are important general requirements:

- ease of use: the different users need to access the system and the system needs to have different user interfaces as data integration with other information systems to avoid re-entering data, e.g. such as enterprise resource planning (ERP), production planning, data history
- robust: needs to show consistent and reliable advice to be accepted by users
- close to reality: needs to represent plant reality (costs, equipment, start-up times) without introducing an unmanageable level of detail
- flexible: needs to be flexible so that adjustments in the changing plant environment (e.g. temporary restraints, updating costs) can be done with little effort.

A utilities optimiser should be able to reliably calculate the benefits of options (on-line or off-line, e.g. 'what-if' scenarios) and contribute to motivating the necessary change(s)(see Section 2.2.5).

The key requirements for a model-based utilities optimiser are:

- a model of the fuel, steam and power generation processes and distribution system. At a minimum, the model must accurately represent:
  - the properties of all fuels, including the lower heating value and composition
  - the thermodynamic properties of all water and steam streams on the facility
  - the performance of all utility equipment over their normal range of operation
- a model of all buy-and-sell contracts that apply to the utilities system
- mixed integer optimisation capability, which enables utility equipment on/off decisions as well as discontinuities in the contract model and/or utilities process model
- online data validation and gross error detection
- open loop
- online optimisation
- the possibility to carry out 'what-if' studies for off-line studies (study impact of projects, study impact of different types of contracts for, e.g. electricity and fuel).

**Applicability**

Simple control systems are applicable even in small installations. The complexity of the system will increase in proportion to the complexity of the process and the site.

Utilities optimisation and management is applicable on sites where there are multiple types of energy usage (steam, cooling, etc.), and various options for sourcing energy, between these energy carriers and/or including in-house generation (including co- and tri-generation, see Section 3.4).

**Economics**

See Examples.

**Driving force for implementation**

Cost is a main driver. The cost savings from a reduction in energy use is complicated by (see Section 5.2) the complexity of tariffs in increasingly deregulated utilities markets, power and fuel trading, and emissions monitoring, management and trading.

| **Business Process** | **Mainly driven by** | |
|---|---|---|
| | **Energy efficiency** | **Energy cost / contracts** |
| **Demand forecasting:** knowledge of the current and predicted future utility demands over given time periods (days, weeks, months, years, depending on process and market variations). Helps minimise:<br>• the use of hot standby (e.g. boilers)<br>• the venting of excess steam<br>• the loss of supply due to insufficient standby or control. | + | |
| **Utilities production planning:** takes demand profiles and develops an optimised production plan based on the availability of utilities. Can be tactical (24 hrs) or strategic (when to start-up or shut down equipment for maintenance) | + | + |
| **Optimal plant operation (on-line optimisation):** while a plan may be developed in advance (e.g. for every 24 hrs) operations can vary and invalidate this. A utilities optimiser can provide real time advice to operations staff on how to operate the system at the lowest cost based on current demands and prices. | + | + |
| **Performance monitoring (utilities equipment):** a utilities optimiser can track the performance of individual items and systems. This can be used to optimise maintenance and cleaning schedules, and warn of operating problems. | + | |
| **Investment planning:** a utilities optimiser can be used to evaluate design options for new equipment and changes to existing equipment in both process systems and the utilities systems, e.g.<br>• deaerator feed-water heating using process heat<br>• choice of drive(motor or steam turbine) or possibly dual process drives to give greater flexibility to balance the steam system<br>• improving condensate return<br>• changing energy supply (e.g. use of low pressure steam to reduce medium pressure steam use)<br>• use of steam to preheat combustion air to furnaces<br>• integration with existing steam network in case a new unit is to be built on the site or modification in existing network in case of closure of units. | + | + |
| **Emissions monitoring, management and trading:** Certain gaseous emissions ($SO_X$ and $CO_2$) can be directly related to fuels burnt. $NO_X$ requires predictive models, as its formation depends on fuel, flame temperature, equipment, etc. A utilities optimiser can include emissions prediction and reporting, where the permit requires this (e.g. for ELV compliance). The optimiser can also support decision making for emission management and trading by predicting demands and corresponding emissions. | + | + |
| **Contract management:** (see Section 5.2): An optimiser provides an operator with data to minimise and move peak demands. | (+) | + |
| **Tariff evaluation:** utilities deregulation has lead to a bewildering array of tariff options. Manual calculation and choice is not sufficiently accurate and rapid, and for large users this is automated. | | + |
| **Power and fuel trading:** process industries are increasingly investing in co- and tri-generation, with the ability to export energy. This complicates tariff evaluation and an optimiser supports efficient energy trading. | | + |
| **Cost accounting:** a utilities optimiser provides accurate cost allocation in real time and also provides true marginal costs. This can support decision making in varying energy sources. | | + |

**Table 2.6: Business process drivers for using a utilities optimiser**

### Examples

1. Schott AG, DE. See Annex 6.

Costs:

- software: about EUR 50 000
- hardware: about EUR 500 /measuring point.

Savings per year:

- peak load lowering at delivery of electricity: about 3 to 5 %
- payback period: about 0.9 to 2 years (dependent on project).

2. Atrium Hospital, Heerleen, NL. See Annex 6
A real-time utilities management system was installed, with an internal ROI of 49 % (at about EUR 75 000 - 95 000/yr on a variable energy cost of about EUR 1.2 million.

Valero Energy Corporation, Refinery, Houston, Texas, US
A utilities optimiser for a petroleum system was installed in 2002. First year benefits have been identified of USD 2.7 million, including reduced imports of NG and electricity.

DSM, chemical plant, Geleen, NL
Benefits have been identified as an ROI of >25 %, with 3 to 4 % saving in total site energy costs, resulting from both energy savings and more favourable contract arrangements with suppliers.

**Reference information**
General information, Valero and DSM examples: [171, de Smedt P. Petela E., 2006]
Schott glass:[127, TWG]
Atrium Hospital [179, Stijns, 2005]

## 2.8 Energy audits

**Description**

In general, an audit is an evaluation of a person, organisation, system, process, project or product. Audits are performed to ascertain the validity and reliability of information, and also to provide an assessment of a system's internal control. Traditionally, audits were mainly concerned with assessing financial systems and records. However, auditing is now used in gain other information about the system, including environmental audits [182, Wikipedia]. An audit is based on sampling, and is not an assurance that audit statements are free from error. However, the goal is to minimise any error, hence making information valid and reliable.

The term 'energy audit' is commonly used, and is taken to mean a systematic inspection, survey and analysis of energy flows in a building, process or system with the objective of understanding the energy dynamics of the system under study. Typically, an energy audit is conducted to seek opportunities to reduce the amount of energy input into the system without negatively impacting the output(s).

In practice, there are wide ranges of types and complexities of energy audit. Different types of audit may be used in different phases of energy management, and/or differing complexity of situations. Differing scopes, degrees of thoroughness and aims are illustrated in Figure 2.8:

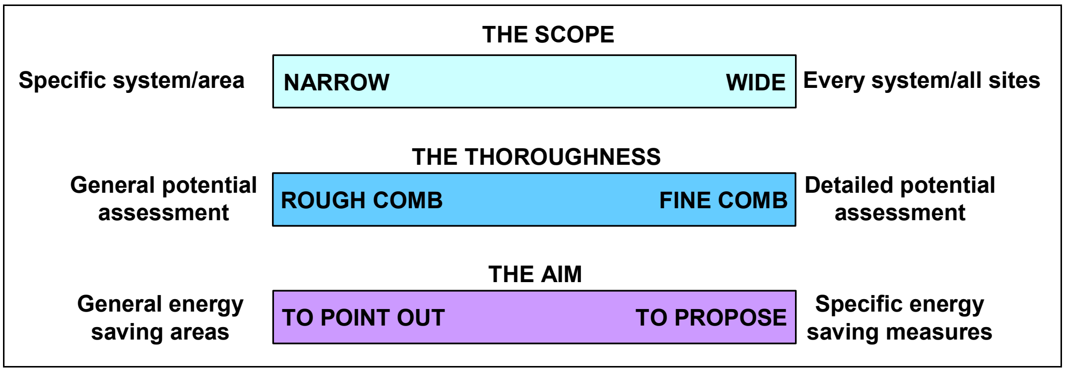


**Figure 2.8: The properties of energy audit models**
**[7, Lytras, 2005]**

Some tools that may be used to assist or standardise energy auditing are listed in Annex 7.

The different energy audit models can be divided into two main types according to their scope:

1. the scanning audit models
2. the analytical models.

Within these two types, there are different models which may be specified according to their scope and thoroughness. In reality, the audit can be specified to meet the needs of the situation.

Some standards exist, usually within auditing companies or energy saving schemes, although there is one national standard, and a CEN standard in preparation.

Similarly to financial audits, energy audits may be carried out by internal or external staff, depending on the aims of the audit, the complexity of the site and the resources available. Some SMEs may not have sufficient in-house experience and staff and use external consultants (particularly if this is made available as part of an initiative, see Chapter 5). Large energy users may have staff allocated to this work, but may also use either external consultants for additional or one-off audits, or create a temporary team from other departments or sites (see Sections 2.2.5 and 2.3).

### (1) The scanning models

The main aim of the scanning energy audit model is to point out areas where energy saving possibilities exist (or may exist) and also to point out the most obvious saving measures. Scanning audits do not go deeply into the profitability of the areas pointed out or into the details of the suggested measures. Before any action can be taken, the areas pointed out need to be analysed further.

A scanning audit model is a good choice if large audit volumes need to be achieved in a short time. These types of audits are usually cheap and quick to carry out. A scanning audit may not bring the expected results for an operator, because it does not necessarily bring actual saving measures ready for implementation but usually suggests further analysis of key areas. There are two main examples of scanning model, described below:

- walk-through energy audit
- preliminary energy audit.

Walk-through energy audit

A walk-through energy audit is suitable for small and medium sized industrial sites if the production processes are not very complicated in the sense of primary and secondary energy flows, interconnected processes, opportunities for re-using lower levels of heat, etc.

A walk-through energy audit gives an overview of the energy use of the site, points out the most obvious savings and also points out the needs for the next steps (supplementary ‘second-phase’ audits).

Preliminary energy audit

The scanning energy audit model for large sites is often called the preliminary energy audit. Audits of this type are typically used in the process industry. Although the main aim of the preliminary energy audit is in line with the walk-through energy audit, the size and type of the site requires a different approach.

Most of the work in the preliminary energy audit is in establishing a clear picture of the current total energy consumption, defining the areas of significant energy consumption and often the probable energy saving measures. The reporting also identifies the areas where supplementary ‘second-phase’ audits are needed and how they should be targeted.

The preliminary energy audit normally needs to be carried out by a team of experts.

Expertise is needed both on the auditing procedure itself as well as on the production process. The preliminary energy audit always requires committed participation from the technical personnel of the site.

### (2) The analytical models

The analytical energy audit models produce detailed specifications for energy saving measures, providing the audited client with enough information for decision-making. Audits of this type are more expensive, require more work and a longer time schedule but bring concrete suggestions on how to save energy. The operator can see the saving potential and no additional surveys are needed.

The analytical models can be divided into two main types:

- selective energy audits, where the auditor is allowed to choose the main areas of interest
- targeted energy audits, where the operator defines the main areas of interest. These are usually
  - system-specific energy audit
  - comprehensive energy audit.

## Selective energy audit

The selective energy audit looks mainly for major savings and does not pay attention to minor saving measures. This audit model is very cost effective when used by experienced auditors but may, in the worst case, be 'cream skimming'. There is always the risk that when a few significant saving measures are found, the rest will be ignored.

## Targeted energy audit

The content of work in the targeted energy audit is specified by detailed guidelines from the operator and this means that most of the systems to be covered by the targeted energy audit are known in advance. The guidelines, set by the operator, may deliberately exclude some areas. The reason for excluding certain areas may be that they are known to be normally non-cost relevant (or more easily dealt with).

The targeted energy audit usually produces a consumption breakdown and includes detailed calculations on energy savings and investments. If the guidelines are adequate, the audit produces a standard report.

From the operator's perspective, there is always a risk if quality control of a targeted energy audit is neglected: the auditors may be tempted to slowly move towards the selective energy audit, because this model always includes less work.

### *System-specific energy audit*

An example of the targeted energy audit at the simplest and smallest is the system specific energy audit. This type of audit has a tightly limited target (one system, device or process), but the thoroughness of the work is usually very high. The benefit of this audit model is that it is possible to specify the expertise for the work, which may be better than a more generalist auditor can provide.

The system specific energy audit produces a detailed description of the system and identifies all saving measures, with options concerning the specific system, and may provide the cost-benefits of the identified options.

A good option is to combine this type of audit with some more comprehensive audit models, e.g. carry out a preliminary energy audit, and subsequently, specific audit(s) of systems where a significant energy saving possibility has been identified.

System specific energy audits give high saving potentials compared to the energy use of the system. The problem is that when looking at only one part of the site the 'bigger picture' is missing and a risk of partial optimisation exists. For example, when studying only the energy efficiency of compressed air or cooling systems, heat recovery opportunities cannot be evaluated because there is no knowledge as to where heat could be used in the most efficient way. Energy systems are usually interrelated and seldom independent.

### *Comprehensive energy audit*

A comprehensive energy audit is a targeted energy audit at the 'widest' end of the scales (in Figure 2.9). It covers all energy usage of the site, including mechanical and electrical systems, process supply systems, all energy using processes, etc. Some minor systems may be excluded, where they have little relevance in proportion to the total energy consumption (for example, doors powered by electric motors)

The difference a comprehensive energy audit to the targeted energy audit is that the targeted energy audit deliberately ignores some areas that are known and specified in advance and the comprehensive energy audit covers virtually all significant energy consumption.

The starting point in a comprehensive energy audit is always an analysis on the detailed breakdown of the total consumption. This type of audit comments on all systems using energy specified at the beginning, regardless of savings being found. It points out all potential saving measures and includes detailed calculations on energy savings and investment costs.

This model also creates a basis for a very standard and detailed reporting which brings some advantages to the operator especially in quality control and monitoring.

**Achieved environmental benefits**
As an energy audit identifies the main areas, operations and types of energy used in a unit/process/site, the reported findings can be used to identify and prioritise the cost effective energy saving opportunities

**Cross-media effects**
None.

**Operational data**
See Description, above.

A French national standard for energy audits is being drafted

**Applicability**
See Description, above.

**Economics**
See Description, above.

**Driving force for implementation**
Cost saving. Adherence to energy saving agreements, etc.

**Examples**
Widely used. A comprehensive-type energy audit for a given organisation can be carried out according to Figure 2.9:

**Reference information**
[92, Motiva Oy, 2005], [40, ADENE, 2005], [31, Despretz, ], [7, Lytras, 2005][165, BESS_EIS]

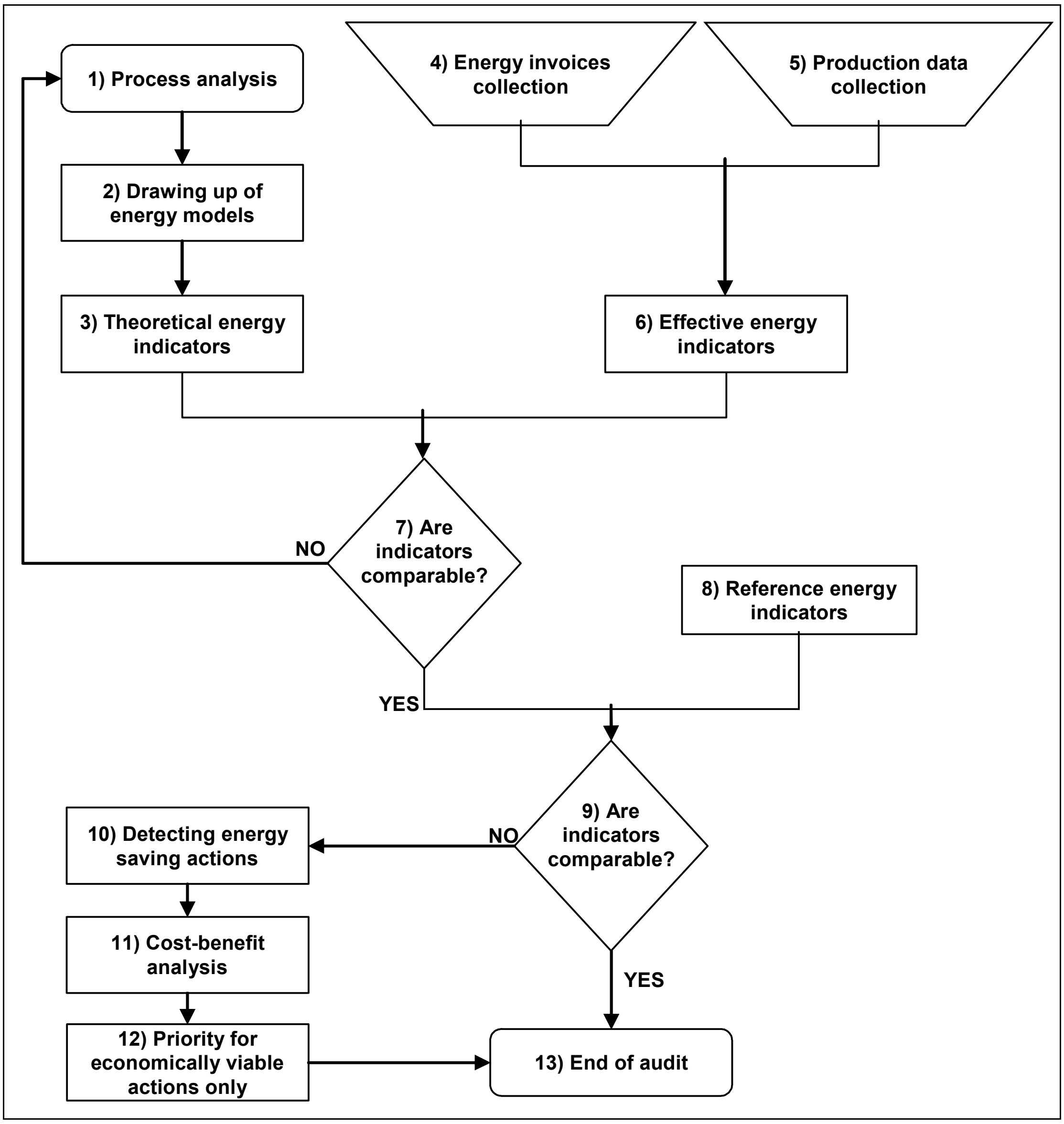


Figure 2.9: Scheme for a comprehensive-type energy audit
[11, Franco, 2005]

## 2.9 Pinch technology

**Description**

Pinch analysis is a methodology for minimising energy consumption in processes by calculating thermodynamically feasible energy targets and achieving them by optimising heat recovery systems, energy supply methods and process operating conditions. It is also known as *process integration, energy integration or pinch methodology.*

All processes consist of hot and cold streams. A hot stream is defined as one that requires cooling, and a cold stream as one that requires heating. For any process, a single line can be drawn on a temperature-enthalpy plot which represents either all the hot streams or all the cold streams of the process. A single line either representing all the hot streams or all the cold streams is called the hot composite curve or the cold composite curve, respectively. The construction of a composite curve is illustrated in Figure 2.10. Two hot streams are shown on a temperature-enthalpy diagram.

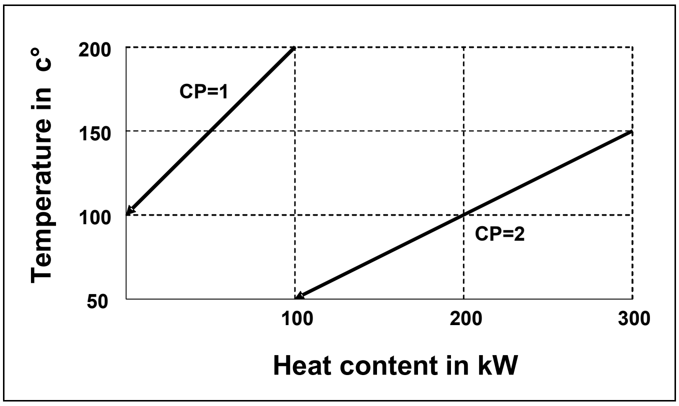


**Figure 2.10: Two hot streams**

Stream 1 is cooled from 200 to 100°C. It has a CP (i.e. mass flowrate x specific heat capacity) of 1; therefore, it loses 100 kW of heat. Stream 2 is cooled from 150 to 50°C. It has a CP of 2; therefore, it loses 200 kW of heat.

The hot composite curve is produced by the simple addition of heat contents over temperature ranges:

- between 200 and 150°C, only one stream exists and it has a CP of 1. Therefore, the heat loss across that temperature range is 50 kW
- between 150 and 100°C, two hot streams exist, with a total CP of 3. The total heat loss from 150 to 100°C is 150 kW. Since the total CP from 150 to 100°C is greater than the CP from 200 to 150°C, that portion of the hot composite curve becomes flatter in the second temperature range from 150 to 100°C
- between 100 and 50°C, only one stream exists, with a CP of 2. Therefore, the total heat loss is 100 kW.

Figure 2.11 shows the hot composite curve.

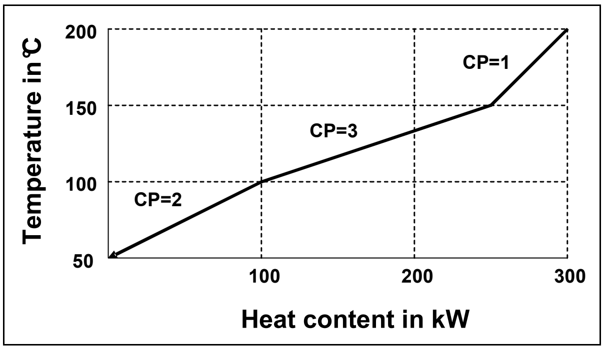


**Figure 2.11: Hot composite curve**

The cold composite curve is constructed in the same way. In practical applications, the number of streams is generally much greater, but these streams are constructed in exactly the same way.

Figure 2.12 shows the hot and cold composite curves plotted on the same temperature-enthalpy diagram. The diagram represents the total heating and cooling requirements of the process.

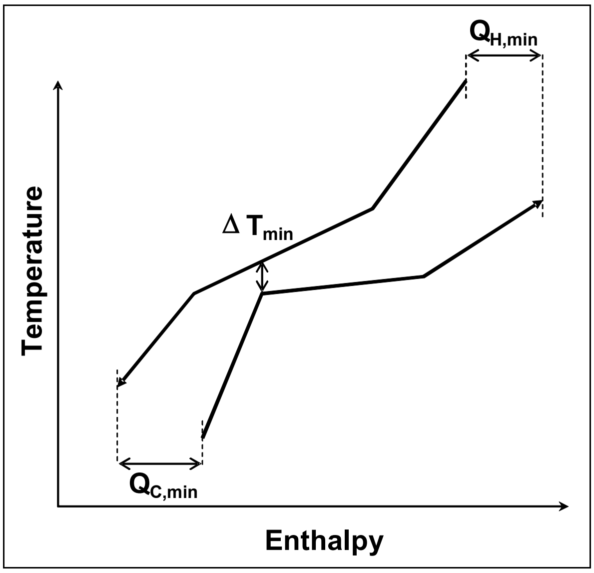


**Figure 2.12: Composite curves showing the pinch and energy targets**

Along the enthalpy axis, the curves overlap. The hot composite curve can be used to heat up the cold composite curve by process-to-process heat exchange. However, at either end an overhang exists such that the top of the cold composite curve needs an external heat source ($Q_{H,min}$) and the bottom of the hot composite curve needs external cooling ($Q_{C,min}$). These are known as the hot and cold utility targets.

The point at which the curves come closest to touching is known as the pinch. At the pinch, the curves are separated by the minimum approach temperature $\Delta T_{min}$. For that value of $\Delta T_{min}$, the region of overlap shows the maximum possible amount of process-to-process heat-exchange. Furthermore, $Q_{H,min}$ and $Q_{C,min}$ are the minimum utility requirements.

Once the pinch and utility targets of a process have been identified, the three 'golden rules' of the pinch methodology can be applied. The process can be considered as two separate systems (see Figure 2.13), a system above the pinch and a system below the pinch. The system above the pinch requires only residual heat and is, therefore, a heat sink, whereas the system below the pinch has heat to reject and is, therefore, a heat source.

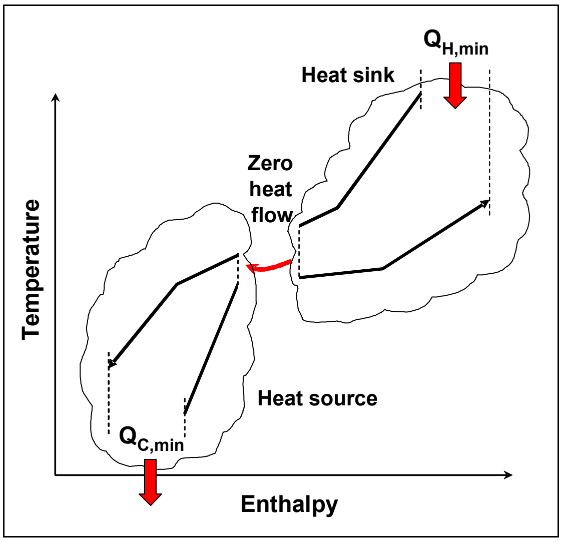


**Figure 2.13: Schematic representation of the systems above and below the pinch**

The three rules are as follows:

- heat must not be transferred across the pinch
- there must be no outside cooling above the pinch
- there must be no outside heating below the pinch.

If the amount of heat travelling across the pinch is α, then an extra amount (α) of hot utility must be supplied and an extra amount of cold utility α is required (see Figure 2.14). Similarly, any outside cooling of the heat sink and any outside heating of the heat source increases the energy requirements.

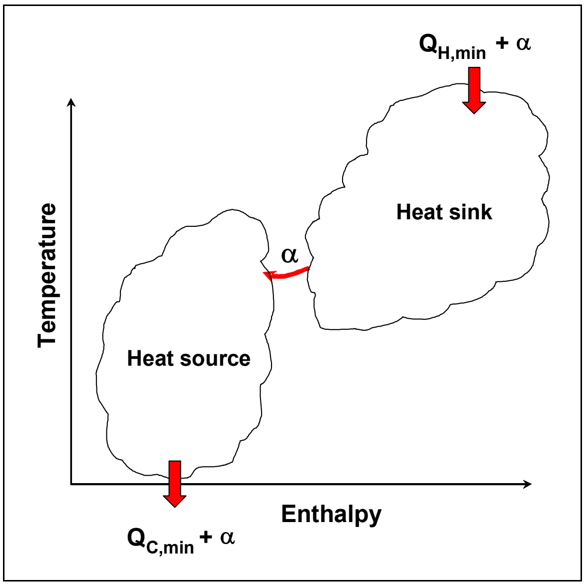


**Figure 2.14: Heat transfer across the pinch from heat sink to heat source**

Thus:

$$T = A - \alpha$$

where T = target energy consumption
A = actual energy consumption
α = cross-pinch heat flow.

To achieve the energy targets, cross-pinch heat flows must be eliminated.

### Achieved environmental benefits

Optimisation of the energy balance on a production site.

### Cross-media effects

None believed likely.

### Operational data

The key to applying the pinch methodology in non-continuous processes is the data extraction. There are no shortcuts; detailed measurements and timings of all the process streams are essential if cost saving (= energy saving) opportunities are to be found.

### Applicability

Pinch technology can be applied to a wide variety of industries with process streams at different temperature levels. It is used in the design of new plants or units, significant upgrades or detailed investigations of a plant's performance, such as:

- energy analysis of process units
- utility plus heat and power system analysis
- heat exchanger network design and analysis
- total site analysis to optimise process and utility integration
- hydrogen and water system analysis.

In its early applications were in the oil refining, petrochemical, and bulk chemical plants, where it showed energy and capital savings. However, recently the technology has been proved across a wide range of processes and industries, including cogeneration, pharmaceuticals, pulp and paper, cement, food, drink and milk (e.g. brewing, coffee making, ice-cream and dairy products), see Examples, below.

Pinch technology has also been used in various kinds of processes including batch, semi-continuous, and continuous operations incorporating various operating parameters, such as different feedstocks, seasonal demand fluctuations, multiple utilities, quality constraints, and environmental constraints.

### Economics

See payback times in Table 2.7.

Pinch technology is often thought to be expensive and difficult. However, for simple problems calculations can be done manually, or using software tools (some are available free of charge). Projects can start from about EUR 5000. The data requirement to perform an analysis is very small, and pinch analysis is a basic element in industrial engineering education.

For more complex situations, an experienced team will be needed to cover pinch analysis, process simulation, cost estimation and plant operation.

### Driving force for implementation

Operating and capital cost savings.

When it has been used in existing operations, there have frequently been process benefits, such as improved plant flexibility, de-bottlenecking, increased capacity and reduced effects of fouling.

## Examples

| Savings from some applications of pinch technology* (Costs: USD, reported Ullman's, 2000) | |
|---|---|
| **Process description** | **Savings** |
| Crude oil unit | Savings of c. \$ $1.75\times10^6$ at 1.6 year payback |
| Large petrochemical complex manufacturing ethylene, butadiene, HDPE, LDPE, and polypropylene | Savings over c. \$ $7.00\times10^6$ with paybacks from 12 to 20 months |
| Tailor-made chemicals, batch process with 30 reactors and over 300 products | Savings of c. \$ $0.45\times10^6$ at paybacks of 3 months to 3 years |
| Sulphur-based speciality chemicals, batch and continuous | 30 % savings to total site energy bill (worth c. \$ $0.18\times10^6$ at paybacks of 9 - 16 months |
| Edible oil refinery, batch operation, wide range of feedstocks | Savings of 70 % of process energy equivalent to c. \$ $0.79\times10^6$ with paybacks from 12 to 18 months and debottlenecking equivalent to 15 % increased capacity |
| Batch processing of dairy products and dried beverages | Savings of 30 % (equivalent to c. \$ $0.20\times10^6$)with payback of less than 1 year |
| Brewery | Savings from 12 % to 25 % of energy costs with paybacks from 9 months to 2 years |
| State-of-the-art whisky distillery | Significant debottleneckling and savings of c. \$ $0.35\times10^6$ with paybacks from 18 months to 2 years |
| Paper mill | Savings of 8 - 20 % of energy bill at paybacks from 1 to 3 years |
| Continuous cellulose acetate processing | savings of c. \$ $0.28\times10^6$ at 1 year payback |
| Continuous dry cement process | Large energy savings |
| * Savings mentioned above are concerned primarily with energy costs. The majority of the companies also benefited from increased throughout and improved process flexibility and operability; the economic value of these benefits is not included in the table above. | |

**Table 2.7: Pinch technology: some examples of applications and savings [Linhoff, Ullman's, 2000]**

Neste Oil in Finland Porvoo and Naantali refineries (www.nesteoil.com)
Borealis Polymers Oy Finland (www.borealisgroup.com)

Refinery (nominal capacity of 4 550 000 tonnes/yr), with the following sections:

- primary distillation (DP3)
- catalytic reforming (RC3)
- liquid petroleum gas (LPG) splitter
- isomerisation (ISO)
- dewaxing and hydrodesulphuration (MDDW+HF1)
- visbreaking and thermal cracking (VB&TC)
- merox unit
- sour water stripper (SW1)
- naphta splitting.

From the analysis of the VCM plant, it was identified that it was possible to use medium pressure steam. This is why the hot utility savings exceeds 100 %. For several processes, it was not possible to save on cold utilities.

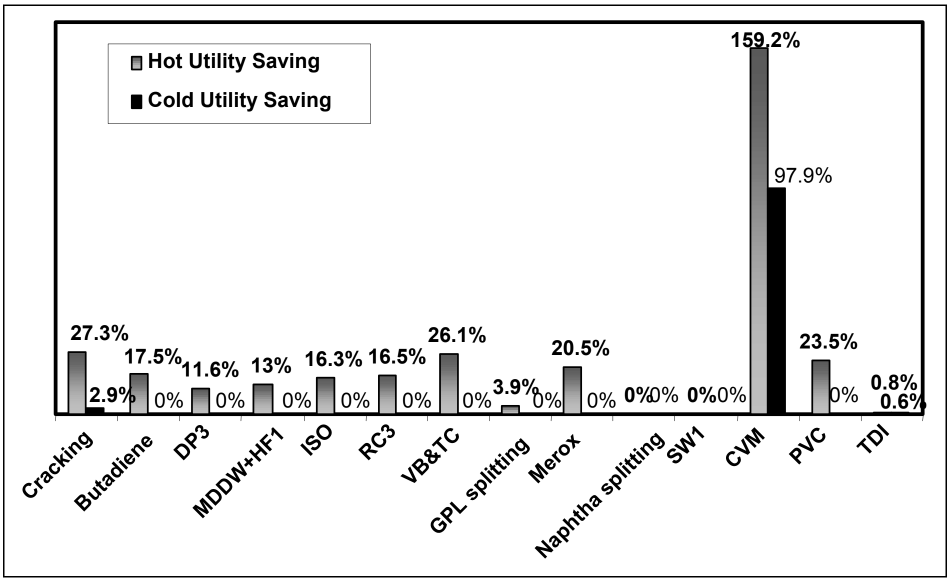


**Figure 2.15: Energy savings identified by pinch analysis**
**[51, Pini, 2005]**

### Reference information

[Linnhoff, Ullmann, 2001], [Linnhoff, 1987] [Wikipedia] [118, KBC],
[119, Neste Jacobs Oy, ], [12, Pini, 2005], [51, Pini, 2005], [67, Marttila, 2005]

Free pinch software: Pinch2.0 from Fraunhofer ISI/Peter Radgen.

It is also a technique considered in other BREFs: OFC, SIC, LVIC-S, REF, etc.

## 2.10 Exergy and enthalpy analysis

### Description

The formula for exergy analysis is given in Section 1.2.2.3
*TWG; No further data has been supplied. Several comments suggested including these analyses, but no further description was supplied or could be found.*

### Achieved environmental benefits

### Cross-media effects

### Operational data

### Applicability

### Economics

### Driving force for implementation

### Examples

### Reference information

[127, TWG]

## 2.11 Sankey diagrams

### Description

Sankey diagrams are a specific type of flow diagram, in which the width of the arrows shown are proportional to the flow quantity. They are a graphical representation of flows such as energy or material transfers in process systems or between processes.

Visually explains visually energy and mass flow data (and can be used to show financial flow data). Particularly useful for communicating data rapidly, especially between staff of different professional backgrounds.

Assists with communication and motivation of staff (see Section 2.1) and maintaining impetus of energy efficiency initiatives (Section 2.2.5).

Inexpensive software can assist with manipulating data into diagram format from sources such as spreadsheets.

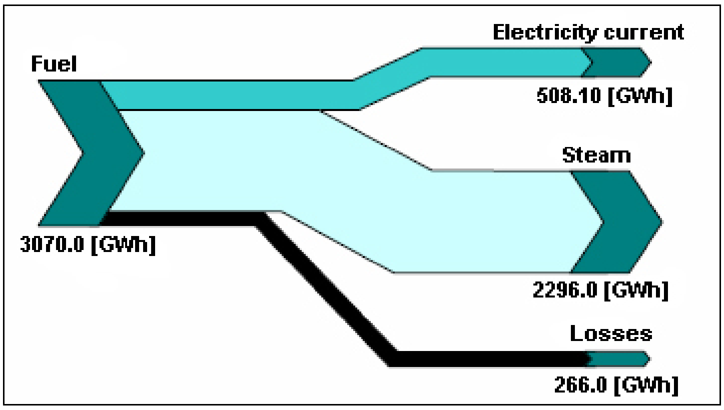


**Figure 2.16: Sankey diagram: Fuel and losses in a typical factory**
**[UBA AT][186, UBA_AT]**

### Achieved environmental benefits

### Cross-media effects

None.

### Operational data

See Description.

### Applicability

All installations which need to demonstrate energy flows.

### Economics

Cheap.

### Driving force for implementation

Helps to communicate energy efficiency data.

**Examples**
Widely used.

**Reference information**
A free tool to create Sankey diagrams from MS Excel™ is available at: http://www.doka.ch/sankey.htm
[127, TWG, , 153, Wikipedia, , 186, UBA_AT]

## 2.12 Benchmarking

**Description**
At its simplest, a benchmark is a reference point. In business, benchmarking is the process used by an organisation to evaluate various aspects of their processes in relation to best practice, usually within their own sector. The process has been described as:

- 'benchmarking is about making comparisons with other companies and then learning the lessons which those companies each show up' (The European Benchmarking Code of Conduct)
- 'benchmarking is the practice of being humble enough to admit that someone else is better at something, and being wise enough to learn how to be as good as them and even better' (American Productivity and Quality Center).

Benchmarking is a powerful tool to help overcome 'paradigm blindness' (which can be expressed as: 'the way we do it is best, because we've always done it this way'). It can therefore be used to assist continuous improvement and maintaining impetus (see Sections 2.2.1 and 2.2.5).

Energy benchmarking takes data that have been collected and analysed (see measurement and monitoring, and audit, Sections 2.7 and 2.8). Energy efficiency indicators are then established that enable the operator to assess the performance of the installation over time, or with others in the same sector. Sections 1.3, 1.4 and 1.5 discuss the issues relating to establishing and using indicators.

It is important to note that the criteria used in the data collection are traceable, and kept up to date.

Data confidentiality may be important in certain cases (e.g. where energy is a significant part of the cost of production). Therefore, it is essential to take into account the views of the participating companies and sector associations to safeguard the confidentiality of company data and to ensure the user-friendliness of the instruments. Confidentiality can be protected by:

- agreement
- presenting data in a way that protects the confidential data (e.g. presenting data and targets aggregated for several installations)
- having data collated by a trusted third party (e.g. trade organisation, government agency, etc.).

Benchmarking may also apply to processes and working methods (see also Operational Excellence, Section 2.2.5, and Examples below).

The energy data gathering should be undertaken carefully. Data should be comparable. In some cases, the data may need correction factors (normalisation). For instance, to take account of feedstock, age of equipment etc (see glass industry benchmarking, below), and these should be agreed at the appropriate level (e.g. nationally, internationally, etc.). Key examples are to ensure that energy is compared on a suitable basis, such as prime energy, on lower calorific value, etc. see Sections 1.3, 1.4 and 1.5.

Assessment can be made on a time-series basis. This:

- illustrates the benefit of a measure (or group of measures) achieves for overall energy consumption (either in-house or to a sector, region, etc.)
- is a simple method which can be applied internally if the required reference data are available, and where it is difficult to establish external benchmarks.

The main disadvantage of the time-series comparison is that the underlying conditions must stay the same to enable an assessment of the energy efficiency.

Assessment can also be made against the theoretical energy or enthalpy demand (see glass industry benchmarking, below). These are calculated from the thermal energies, melting energies, kinetic or potential energies, for a process. They:

- are a good approach for initial estimates
- should be relatively easy to use with relevant experience
- should show the distance between actual energy usage and the theoretical demand (this may be coupled to a time-series comparison to help establish the cost-benefit of further measures).

The main disadvantage is that the calculation can never take all the specific characteristics of an operation into account.

**Achieved environmental benefits**
A powerful tool to assist implementation of energy efficiency measures on an ongoing basis.

**Cross-media effects**
None.

**Operational data**
See Description.

**Applicability**
Benchmarking can be readily used by any installation, group of companies, installations or trade association. It may also be useful or necessary to benchmark individual units, processes or utilities, such as those discussed in Chapter 3 (see also Sections 1.3, 1.4 and 1.5).

**Economics**
The main cost may be in the data gathering. However, further costs are incurred in establishing data on a wider basis, and modelling normalisation data.

**Driving force for implementation**
Cost savings.

**Examples**
Details of these benchmarking activities are given in Annex 8.

Austrian Energy Agency
Austrian Energy Agency’s (AEA) report ‘Energy benchmarking at the company level, company report diary’ gives benchmarking factors other than specific energy consumption.

Scheme for SMEs in Norway
Norway has a web-based benchmarking scheme for SMEs.

Benchmarking covenants, Netherlands (A similar scheme operates in Flanders Province, Belgium)
In the Netherlands, long-term agreements (covenants) between the government and large companies (consuming over 0.5 PJ/year) are based on benchmarking.

Glass industry benchmarking
The glass industry is investigating several methods to identify the most energy effect glass-melting operations; and some results have been published:

- best practice methods and application of energy balances
- determination of the theoretical energy or enthalpy demand and the practically lowest level of energy consumption
- benchmarking of specific consumption of industrial glass furnaces
- development of new melting and fining techniques.

**Reference information**
[10, Layer, 1999] [13, Dijkstra, ] [108, Intelligent Energy - Europe, 2005] [127, TWG, , 156, Beerkens, 2004, 157, Beerkens R.G.C. , 2006] [163, Dow]

## 2.13 EMAT (energy manager's tool)

**Description**

EMAT is a working tool for energy managers in SMEs, which allows them to quantify the energy savings potential of several horizontal technologies in a single application. The tool was developed in the EC energy efficency programme (SAVE), and results have been distributed as a multimedia application based on CD-ROM support. Table 2.8 includes the areas covered by the application and also the practical examples included in this CD.

| Area | Practical examples |
|---|---|
| **Compressed air** | • compressors<br>• leaks<br>• energy recovery<br>• lubricated and oil free compressor |
| **Thermal insulation** | • thermal insulation of cylindrical surfaces<br>• thermal insulation of spherical surfaces<br>• thermal insulation of plane surfaces |
| **Electrical motors** | • performance of an a/c asynchronous induction motor<br>• a/c asynchronous motors of a small size<br>• motor drive of a machine<br>• common a/c asynchronous motors<br>• a/c asynchronous induction motors<br>• asynchronous three phase motors<br>• a/c asynchronous induction motors (important rating)<br>• drive of a machine with many cycles per hour<br>• starting very large motors<br>• starting medium and large motors<br>• motor pump<br>• repeated cycles with short working periods<br>• internal transportation trucks in a workshop |
| **Boilers** | • thermal efficiency of a saturated steam boiler<br>• blowdown of a saturated steam boiler<br>• workflow of steam boiler malfunctions |

**Table 2.8: Areas covered by EMAT**

**Achieved environmental benefits**

Assists the identification of energy saving measures in SMEs.

**Cross-media effects**

None.

**Operational data**

See Description.

**Applicability**
This tool is applied mainly for SMEs from industry.

Results of implementing this tool include:

- overall, around 63 % of the users agree that this kind of application is good for identifying energy saving measures within the areas covered
- 75 % of the users agree that the examples given in EMAT are useful
- the majority of the users agree that EMAT is user friendly, although 40 % of them felt difficulties using calculation examples
- 70 % of the companies did not use EMAT with data from their own installations.

Nevertheless, those that used it with their own data were satisfied with the results.

There is a risk that this tool may drive a bottom-up approach based on examining individual components, rather than a top-down approach, considering whole systems and their optimisation.

**Driving forces for implementation**
The experience obtained over several years from hundreds of energy audits performed in different countries for SMEs revealed that industrialists companies still disregard high energy savings potentials, (around 5 %), characterised by simple optimisation measures with very low investment. These kinds of measures are related to simple actions performed upon horizontal technologies such as compressed air, combustion parameters, boilers, insulation, etc.

**Economics**
The software is available without any charge.

**Examples**
Widely used.

**Reference information**
[38, ADENE, 2005]

## 2.14 Other tools

Other tools that may be used at a site level are listed in Annex 9.

# 3 TECHNIQUES TO CONSIDER FOR ACHIEVING ENERGY EFFICIENCY IN ENERGY-USING SYSTEMS, PROCESSES, OR ACTIVITIES

A hierarchical approach has been used for Chapters 2 and 3:

- Chapter 2 describes techniques to be considered at the level of a entire installation with the potential to achieve optimum energy efficiency
- Chapter 3 sets out techniques to be considered at a level below installation: primarily the level of energy-using systems (e.g. compressed air, steam) or activities (e.g. combustion), and subsequently at the lower level for some energy-using component parts or equipment (e.g. motors).

Management systems, process-integrated techniques and specific technical measures are included in the two chapters, but these three measures overlap completely when seeking the optimum results. Many examples of an integrated approach demonstrate all three types of measures. This makes the separation of techniques for description somewhat difficult and arbitrary.

Neither this chapter nor Chapter 2 gives an exhaustive list of techniques and tools, and other techniques may exist or be developed which may be equally valid within the framework of IPPC and BAT. Techniques may be presented singly or as combinations (both in this chapter and in Chapter 2) and supported by information given in Chapter 1 to achieve the objectives of IPPC.

Where possible, a standard structure is used to outline each technique in this chapter and in Chapter 2, as shown in Table 3.1. Note that this structure is also used to describe the systems under consideration, such as (at installation level) energy management, and (at a lower level) compressed air, combustion, etc.

| Type of information considered | Type of information included |
|---|---|
| Description | Short descriptions of energy efficiency techniques presented with figures, pictures, flow sheets, etc. that demonstrate the techniques |
| Achieved environmental benefits | Main environmental impacts, in particular energy use but including, water, raw material savings, as well as production yield increases, etc. addressed by the technique |
| Cross-media effects | Any side-effects and disadvantages caused by implementation of the technique. Details on the environmental problems of the technique in comparison with others |
| Operational data | Performance data on energy and other consumptions (raw materials and water) and on emissions/wastes. Any other useful information on how to operate, maintain and control the technique, including safety aspects, operability constraints of the technique, output quality, etc. |
| Applicability | Consideration of the factors involved in applying and retrofitting the technique (e.g. space availability, process specific) |
| Economics | Information on costs (investment and operation) and related energy savings, EUR kWh (thermal and/or electricity) and other possible savings (e.g. reduced raw material consumption, waste charges) also as related to the capacity of the technique |
| Driving force for implementation | Reasons (other than IPPCD) for implementation of the technique (e.g. legislation, voluntary commitments, economic reasons) |
| Examples | Reference to at least one situation where the technique is reported to be used |
| Reference information | Sources of information and literature for more details on the technique |

**Table 3.1:The information breakdown for systems and techniques described in Chapters 2 and 3**

## 3.1 Combustion

Combustion or burning is a complex sequence of exothermic chemical reactions between a fuel and an oxidant accompanied by the production of heat or both heat and light in the form of either a glow or flames.

In a complete combustion reaction, a compound reacts with an oxidising element, and the products are compounds of each element in the fuel with the oxidising element. In reality, combustion processes are never perfect or complete. In flue-gases from the combustion of carbon (coal combustion) or carbon compounds (hydrocarbons, wood, etc.) both unburned carbon (as soot) and carbon compounds (CO and others) will be present. Also, when air is the oxidant, some nitrogen will be oxidised to various nitrogen oxides ($NO_X$) with impacts on the environment [122, Wikipedia_Combustion, 2007].

The heat energy resulting from the combustion of fossil fuels is transferred to the working medium. The heat losses can be categorised as [125, EIPPCB]:

- losses via the off-gas. These depend on the flue-gas temperature, air mix, fuel composition and the level of fouling of the boiler
- losses through unburned fuel, the chemical energy of that which is not converted. Incomplete combustion causes CO and hydrocarbons to occur in the flue-gas
- losses through conduction and radiation. (In steam generation, these mainly depend on the quality of insulation of the steam generator).

In addition, for steam generation:

- losses through unburned material in the residues, such as carbon in bottom and fly ash
- losses via the bottom and fly ash from a DBB and the slag and fly ash from a WBB.

In addition to the heat losses, the energy consumption needed for the operation of auxiliary machinery (fuel transport equipment, coal mills, pumps and fans, ash removal systems, cleaning of the heating surfaces, etc.) also has to be taken into consideration.

*Choice of combustion techniques*
Common techniques for energy generation in large combustion plants (>50 MW thermal power) and with different fuels (e.g. biomass and peat, liquid or gaseous fuels) are discussed in detail in the LCP BREF. The LCP BREF states that the information provided is also valid for smaller ones (as a plant of >50 MW thermal power may consist of more than one smaller units). Therefore this section (of this BREF) focuses on the combustion techniques not dealt in the LCP BREF or those which may be of particular generic interest.

Steam-side issues are fully discussed in Section 3.2, although a partial overlap with this section cannot be avoided.

*Combustion installations*
The combustion installations discussed in this section are heating devices or installations using the combustion of a fuel to generate and transfer heat to a given process. This includes the following applications:

- boilers to produce steam or hot water
- process heaters, for example to heat up crude oil in distillation units, to achieve steam cracking in petrochemical plants, or steam reforming for the production of hydrogen
- kilns where solid granular materials are heated at elevated temperatures to induce a chemical transformation, for example cement kilns.

In all of these applications, energy can be managed by control on the process parameters and control on the combustion side. Energy management strategies relative to the process depend on the process itself and are not considered here.

*Scope*
The following information is relevant for both flame combustions (using a burner) and combustion in a fluidised bed. It addresses energy management on the combustion side only, from the fuel and air inlets to the flue-gases exhaust at the stack.

*General energy balance*
The general energy balance of a combustion installation when process temperatures are low, is given in Figure 3.1.

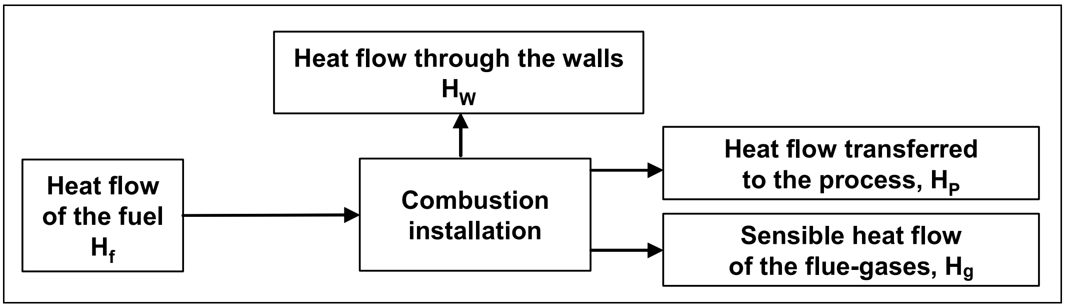


**Figure 3.1: Energy balance of a combustion installation**

*Explanation of the different energy flows*

Heat flow of the fuel $H_f$ is based on its mass flowrate and its calorific value (the amount of energy that is liberated by the combustion of a specific mass of fuel). The calorific value is expressed as MJ/kg. The higher or gross heating value (HCV, or higher calorific value HCV) of a fuel is the total heat developed after the products of combustion are cooled to the original fuel temperature. The lower heating value (LCV) is the total heat produced on combustion less the energy in the uncooled products of combustion, including uncondensed water vapour. The LCV of a fuel is typically 5 – 10 % less than the HCV. Typical values of calorific values of current fuels are given in Table 3.2.

| | **HCV (HCV)** | | **LCV (LCV)** | |
|---|---|---|---|---|
| | **MJ/kg** | **MJ/Nm$^3$** | **MJ/kg** | **MJ/Nm$^3$** |
| **Natural gas (NG)** | | 40.3 | | 34.5 – 36.3* |
| **LPG** | 49.6 | | 45.8 | |
| **Diesel oil** | 44.7 | | 41.9 | |
| **Heavy fuel oil** | 43.0 | | 40.6 | |
| **Coal** | 24 – 32 | | | |
| **Wood** | 12 – 15 | | 8 – 13 | 8 – 13 |
| **Peat** | | | 9 – 13 | 9 – 13 |

* The values for LCV and HCV depend on the source of NG. Different sources for different natural gas compositions

**Table 3.2: Higher and lower calorific values of certain fuels**

The heat transferred to the process $H_p$ is the actual duty of the combustion system. It is made of sensible heat (increase of temperature), latent heat of vaporisation (if the heated fluid is partially or completely vaporised), and chemical heat (if an endothermic chemical reaction occurs).

The waste heat flow of the flue-gases $H_g$ is released to the air and lost. It is based on the flowrate of the flue-gases, its heat capacity, the latent heat of the water formed by combustion and present in the flue-gases and its temperature. The flowrate of flue-gases can be divided into two parts:

- the 'stoichiometric flow' of $CO_2$ and $H_2O$ which results from the combustion reactions and its associated nitrogen (this stoichiometric flow is proportional to $H_f$[9]) and
- the flow of excess air, which is the amount of air introduced in excess over the stoichiometric one in order to achieve complete combustion. There is a direct relation between air excess and the concentration of oxygen in the flue-gases.

The heat flow through the walls $H_W$ is the energy that is lost to the surrounding air by heat transfer from the furnace/boiler outer surface to the ambient air.

Basically, the conservation of energy gives :

**Eq 6**

$$H_f = H_p + H_g + H_w$$

---

[9] For a given fuel composition, $H_f$ and the stoichiometric flowrate are both proportional to the fuel flowrate, so they are proportional to each other. One cannot control the stoichiometric flowrate without changing $H_f$. As the aim is to reduce $H_f$ for a given $H_p$ (energy efficiency), the stoichiometric flowrate is not a parameter which can be varied to reduce $H_f$; it is the result of having changed $H_f$. Conversely, the excess airflow does not depend on $H_f$, and may be varied independently.

This is a generic balance, which can be adapted case by case:

- depending on the configuration, other energy flows may have to be included in the balance. This is the case if other materials are withdrawn from the furnace, for example hot ashes in coal combustion, if water is injected into the combustion chamber to control emissions or to take account of the energy input into the combustion air
- this balance assumes that combustion is complete: this is reasonable as long as unburned components like carbon monoxide or carbonaceous particulates are in small quantities in the flue-gases, which is the case when the installation matches the emission limits[10].

The energy efficiency of a combustion installation

Basically, the energy efficiency of a combustion installation is the ratio of the duty to the energy input by the fuel:

**Eq 7**

$$\eta = H_p / H_f$$

Or combining with equation 6:

**Eq 8**

$$\eta = 1 - \frac{H_g + H_w}{H_f}$$

Both formulas can be used, but it is generally more practical to use the second which shows the amount of lost energies where savings can be obtained. Strategies towards energy efficiency are based on reducing heat flows lost through the walls or in the flue-gases.

An improvement in the energy efficiency of a combustion installation has a benefit of $CO_2$ emissions if it induces a reduction of the fuel consumption. In that case, the $CO_2$ is reduced in proportion to the carbon content of the fuel. However, the improvement of efficiency may also be used to increase the duty while keeping the same fuel flowrate (higher $H_p$ for the same $H_f$ in equation 7. This clears/unblocks the production unit while improving the energy efficiency. In that case, there is a $CO_2$ specific emission reduction (referred to the production level) but no $CO_2$ emissions reduction in absolute value (see Section 1.4.1).

---

[10] In a pulverised coal power plant the unburned carbon in fly ash, under normal current conditions, is below 5 %.

## 3.1.1 Reduction of the flue-gas temperature

**Description**

This can be achieved by:

- increasing heat transfer to the process by increasing either the heat transfer rate, (installing turbulators or some other devices which promote the turbulence of fluids exchanging heat), or increasing or improving the heat transfer surfaces
- heat recovery by combining an additional process (for example, steam generation by using economisers, see Section 3.2.4) to recover the waste heat in the flue-gases
- installing an air preheater or preheating the fuel by exchanging heat with flue-gases (see Section 3.1.1.1). Note that the process can require air preheating when a high flame temperature is needed (glass, cement, etc.)
- cleaning of heat transfer surfaces that are progressively covered by ashes or carbonaceous particulates, in order to maintain high heat transfer efficiency. Soot blowers operating periodically may keep the convection zones clean. Cleaning of the heat transfer surfaces in the combustion zone is generally made during inspection and maintenance shutdown, but on-line cleaning can be applied in some cases (e.g. refinery heaters)
- lowering the thermal power of the burner by decreasing the flowrate of fuel, e.g. by installing a less powerful nozzle for liquid fuels, or reducing the feed pressure for gaseous fuels.

**Achieved environmental benefits**

Energy saving.

**Cross-media effects**

Reducing flue-gas temperatures may be in conflict with air quality in some cases, e.g:

- preheating combustion air leads to a higher flame temperature, with a consequence of an increase of $NO_X$ formation that may lead to levels that are higher than the emission limit value. Retrofitting an existing combustion installation to preheat the air may be difficult to justify due to space requirements, the installation of extra fans, and the addition of a $NO_X$ removal process if $NO_X$ emissions exceed emission limit values. It should be noted that a $NO_X$ removal process based on ammonia or urea injection induces a potential of ammonia slippage in the flue-gases, which can only be controlled by a costly ammonia sensor and a control loop, and, in case of large load variations, adding a complicated injection system (for example, with two injection ramps at different levels) to inject the $NO_X$ reducing agent always in the right temperature zone
- gas cleaning systems, like $NO_X$ or $SO_X$ removal systems, only work in a given range of temperature. When they have to be installed to meet the emission limit values, the arrangement of gas cleaning and heat recovery systems becomes more complicated and can be difficult to justify from an economic point of view
- in some cases, the local authorities require a minimum temperature at the stack to ensure proper dilution of the pollutants and to prevent plume formation.

**Operational data**

The lower the flue-gas temperature, the better the energy efficiency. Nevertheless, certain drawbacks can emerge when the flue-gas temperatures are lowered below certain levels. In particular, when running below acid dew point (a temperature below which the condensation of water and sulphuric acid occurs, typically 110 to 170 C, depending essentially on the fuel's sulphur content) damage of metallic surfaces may be induced. Materials which are resistant to corrosion can be used and are available for oil and gas fired units although the acid condensate may require collection and treatment.

**Applicability**
The strategies above – apart the periodic cleaning – require additional investment and are best applied at the design and construction of the installation. However, retrofitting an existing installation is possible (if space is available) and the extra costs are often recovered within a short time.

Some applications may be limited by the difference between the process inlet temperature and the flue-gas exhaust temperature. *TWG: What is a 'sufficient' difference between the temperatures?*

Recovery of heat is always dependent on there being a suitable use (see Section 3.3).

**Economics**
Even when recovering heat below the dew point, payback time is under five years.

**Driving force for implementation**
Increased process efficiency where there is direct heating (e.g. glass, cement).

**Examples**
Widely used.

**Reference information**
[17, Åsbland, 2005, 26, Neisecke, 2003, 122, Wikipedia_Combustion, 2007, 125, EIPPCB]

### 3.1.1.1 Installing an air preheater

**Description**
Besides an economiser (Section 3.2.4), an air preheater (air-air heat exchanger) can also be installed. The air preheater or APH heats the air which flows to the burner. This means flue-gases can be cooled down even more, as the air is often at ambient temperature. A higher air temperature improves combustion, and the general efficiency of the boiler will increase. In general for every decrease of 20 C in flue-gas temperature, a 1 % increase in efficiency can be achieved.

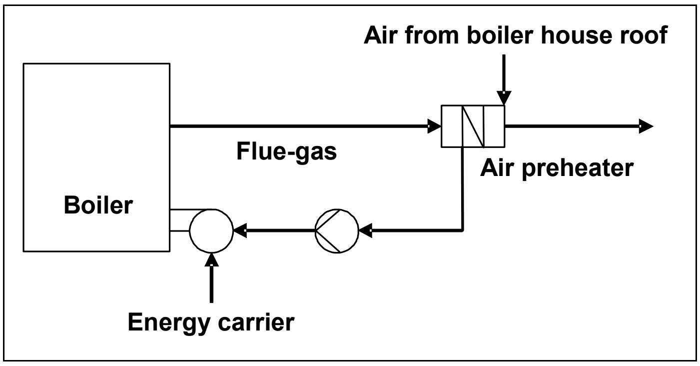


**Figure 3.2: Scheme of a combustion system with an air preheater**

A less efficient but simpler way of preheating might be to install the air intake of the burner on the ceiling of the boiler house. Generally the air here is often 10 to 20°C warmer compared to the outdoor temperature. This might compensate in part for efficiency losses.

Another solution is to draw air for the burner via a double walled exhaust pipe. Flue-gases exit the boiler room via the inner pipe, air for the burner is drawn via the second layer. This can preheat the air via losses from the flue-gases.

### Achieved environmental benefits

In practice an APH can raise efficiency by 3 to 5 %.

Other benefits of an APH might be:

- the hot air can be used to dry fuel. This is especially applicable for coal or organic fuel
- a smaller boiler can be used when taking into account an APH at the design stage.

### Cross-media effects

There are, however, also some practical disadvantages related to an APH, which often stand in the way of installation:

- the APH is a gas-gas heat exchanger, and thus takes up a lot of space. The heat exchange is also not as efficient as a gas-water exchange
- a higher drop pressure of the flue-gases means the ventilator of the burner has to provide higher pressure
- the burner must ensure that the system is fed with preheated air. Heated air uses up more volume. This also poses a bigger problem for flame stability
- higher emissions of $NO_X$ due to higher flame temperatures.

### Operational data

Feeding the burner with heated air has an impact on the amount of flue-gas losses in the boiler.

The percentage of flue-gas losses is generally determined using the Siegert formula:

$$W_L = c \cdot \frac{t_{gas} - t_{air}}{\% \, CO_2}$$

where:

| | |
|---|---|
| $W_L$ | the flue-gas losses, in % of the burning value (%) |
| c | the Siegert coefficient |
| $t_{gas}$ | the flue-gas temperature measured (°C) |
| $t_{air}$ | supply air temperature |
| $\% \, CO_2$ | measured $CO_2$ concentration in the flue-gases expressed as a percentage. |

The Siegert coefficient depends on the flue-gas temperature, the $CO_2$ concentration and the type of fuel. The various values can be found in Table 3.3 below:

| Type of fuel | Siegert coefficient |
|---|---|
| Anthracite | $0.6459 + 0.0000220 \times t_{gas} + 0.00473 \times CO_2$ |
| Heavy fuel | $0.5374 + 0.0000181 \times t_{gas} + 0.00717 \times CO_2$ |
| Gasoline | $0.5076 + 0.0000171 \times t_{gas} + 0.00774 \times CO_2$ |
| Natural gas (LCV) | $0.385 + 0.00870 \times CO_2$ |
| Natural gas (HCV) | $0.390 + 0.00860 \times CO_2$ |

**Table 3.3: Calculation of the Siegert coefficient for different types of fuel**

Example: a steam boiler fired with high quality natural gas has the following flue-gas data: $t_{gas}$ = 240 C and $CO_2$ = 9.8 %. The air supply is modified and the hotter air near the ceiling of the boiler house is taken in. Previously the air was taken in at outdoor temperature.

The average outdoor temperature is 10 C, while the annual average temperature near the ceiling of the boiler house is 30 C.

The Siegert coefficient in this case is: 0.390 + 0.00860 x 9.8 = 0.4743.

Prior to the intervention, the flue-gas loss was:

$$W_R = 0.4743 \times \frac{240 - 10}{9.8} = 11.1\ \%$$

After the intervention this becomes:

$$W_R = 0.4743 \times \frac{240 - 30}{9.8} = 10.2\ \%$$

This amounts to an increase in efficiency of 0.9 % where this can be achieved simply, e.g. by using new equipment.

**Applicability**

The installation of an air preheater is cost effective for a new boiler. The change in air supply or the installation of the APH often is limited due to technical reasons or fire safety. The fitting of an APH in an existing boiler is often too complex and has a limited efficiency.

Air preheaters are gas-gas heat exchangers, whose designs depend on the range of temperature. Air preheating is not possible for natural draught burners.

Design depends on the range of temperatures.

Not applicable to natural draught burners.

**Economics**

In practice, the possible savings from combustion air preheating amount to several per cent of the steam volume generated. Therefore, the energy savings even in small boilers can be in the range of several GWh per year. For example, with a 15MW boiler savings of roughly 2 GWh/yr, some EUR 30 000/yr and about 400 t $CO_2$/yr can be attained.

| | Unit | Value |
|---|---|---|
| Energy savings | MWh/yr | Several thousand |
| $CO_2$ reduction | t/yr | Several hundred |
| Savings in EUR | EUR/yr | Tens of thousands |
| Annual operating hours | h/yr | 8700 |

**Table 3.4: Possible savings in combustion air preheating**

**Driving force for implementation**

Increased energy efficiency of processes.

**Examples**

**Reference information**

[29, Maes, 2005], [16, CIPEC, 2002]

## 3.1.2 Reducing the mass flow of the flue-gases by reducing the excess air

### Description

Excess air can be minimised by adjusting the airflowrate in proportion to the fuel flowrate. The measurement of oxygen content in the flue-gases by an automatic instrument is of great help to control excess air. Depending on how fast the heat demand of the process fluctuates, excess air can be manually set or automatically controlled. However, in all cases, at least the stoichiometric amount of $O_2$ should be used, as otherwise the flue-gas released to air may create an explosive environment. For safety reasons, there should therefore always be some excess air present (typically 1 – 2 % for gas and 10 % for liquid fuels).

The required excess air ratio is fuel dependent and this dependence increases for solids, so the choice of an appropriate fuel is another option to reduce the excess air in the combustion process.

### Achieved environmental benefits

Energy saving.

### Cross-media effects

As excess air is reduced, unburned components like carbonaceous particulates, carbon monoxide and hydrocarbons are formed and may exceed emission limit values. This limits the possibility of energy efficiency gain by reducing excess air. In practice, excess air is adjusted to values where emissions are below the limit value.

### Operational data

### Applicability

The minimum excess air that is reachable to maintain emissions within the limit depends on the burner and the process.

Note that the excess air will increase when burning solid wastes. However, waste incinerators are constructed to provide the service of waste combustion, and are optimised to waste as a fuel.

### Economics

The choice of fuels is often based on cost.

### Driving force for implementation

Achieves higher process temperature, especially when direct firing.

### Examples

Some cement and lime plants.

### Reference information

[91, CEFIC, 2005, 125, EIPPCB]][126, EIPPCB]

### 3.1.3 Reducing the mass flow of the flue-gases by firing with oxygen

**Description**

Oxygen is used instead of ambient air. The oxygen is either extracted from air on the site, or more usually, bought in bulk. As air is about 80 % nitrogen, the mass flow of gases is reduced accordingly.

**Achieved environmental benefits**

- increased energy efficiency of the combustion process
- reduced $NO_X$ emissions, as nitrogen levels at the burners are considerably reduced.

**Cross-media effects**

The energy requirement to concentrate oxygen from the air is considerable, and this should be included in any energy calculations (see Section 1.3.5.1). The glass industry reports the improved energy efficiency of the process is almost exactly offset by the energy requirement for producing the oxygen.

**Operational data**

**Applicability**

**Economics**

**Driving force for implementation**

Increased furnace temperatures.

**Examples**

Used in the glass industry.

**Reference information**

[157, Beerkens R.G.C. , 2006]

### 3.1.4 Reducing heat losses by insulation

**Description**

The heat losses through the walls of the combustion system are determined by the diameter of the pipe and the thickness of the insulation. An optimum insulation thickness which relates energy consumption with economics should be found in every particular case.

Efficient thermal insulation to keep heat losses through the walls at a minimum is normally achieved at the commissioning stage of the installation. However, insulating material may progressively deteriorate, and must be replaced after inspection following maintenance programmes. Some techniques using infrared imaging are convenient to identify the zones of damaged insulation from outside while the combustion installation is in operation in order to prepare repairing planning during shutdown.

**Achieved environmental benefits**

Energy efficiency.

**Cross-media effects**

Use of insulation material.

**Operational data**

**Applicability**

**Economics**

Low cost, especially if carried out at shutdowntimes. Insulation repair can be carried out during campaigns.

**Driving force for implementation**

Maintaining process temperature.

**Examples**

Insulation repair is carried out during campaigns in steel and glass industries.

**Reference information**

[91, CEFIC, 2005]

### 3.1.5 Reducing losses through furnace doors

**Description**

Heat losses can also occur via furnace openings for loading/unloading.

*TWG comment: no further data supplied. Should this be considered?*

**Achieved environmental benefits**

**Cross-media effects**

**Operational data**

**Applicability**

**Economics**

**Driving force for implementation**

**Examples**

**Reference information**

[127, TWG]

### 3.1.6 Drying biomass to be used as a fuel

Fuel can be dried using surplus energy, see LCP BREF.

## 3.2 Steam systems

[123, US_DOE]

*NB. The above reference gave lots of data in US/Imperial units. We wish to check the TWG are content with the examples and data, before spending much time on converting these, although most of the examples are in the Annexes. Also, some data are calculated in round numbers in these units, and will appear strange in SI units. We would therefore like the TWG's opinion whether to leave the data in US/Imperial units, recalculate in SI units, or if the TWG can identify replacement data in SI units.*

*This section needs re-ordering to coincide with the overview in table 3.2.2, and may need minor sections adding, e.g. boiler refractory, etc.*

### 3.2.1 General features of steam

**Description**

Steam is one of the possible energy carriers in fluid-based heating systems. Other common energy carriers are water and thermal oil. Water can be used where the required temperature(s) do not exceed 100 C, and pressurised water (to avoid boiling) can be used for temperatures above 100 C, in some cases even over 180 C. Thermal oils have a higher boiling point (and have been developed to have longer lifetimes). Steam has various advantages which are described below, including its use in many direct contact applications.

These advantages include low toxicity, safety use with flammable or explosive materials, ease of transportability, high efficiency, high heat capacity, and low cost with respect to the other alternatives. Steam holds a significant amount of energy on a unit mass basis (2300 - 2900 KJ/Kg) that can be extracted as mechanical work through a turbine or as heat for process use. Since most of the heat content of the steam is stored as latent heat, large quantities of heat can be transferred efficiently at a constant temperature, which is a useful attribute in many process heating applications (see Section 1.2.2.4). Steam is also discussed in the LCP BREF.

The transition from water to steam conditions requires a large quantity of energy, which is stored in latent form. This makes it possible to achieve a sizeable heat transfer in a small surface area when using steam in comparison with other heating fluids:

- water 4000 $W/m^2°C$
- oil 1500 $W/m^2°C$
- steam >10000 $W/m^2$ C.

In the two-phase boundary for the water liquid-gas system represented by a straight line in the phase diagram (see Figure 1.4), steam pressure is directly related to temperature. Temperature can be adapted easily by modifying the pressure. Working at high or low pressure has different effects on the installation (see Operational data, below). The steam pressure of the installation thus needs to be carefully considered in order to achieve an optimisation between reliability and energy efficiency.

The many advantages that are available from steam are reflected in the significant amount of this type of energy that industry uses to generate it. For example, in 1994, industry used about 5988 trillion kJ of steam energy, which represented about 34 % of the total energy used in industrial applications for product output. Some examples of the energy used to generate steam in different industries is shown in Table 3.5. *TWG: we are not happy with the use of trillion, which is confusing. Can the TWG assist with a correct figure in TJ or PJ, and more up to date than 1994?*

| Industry | Energy to generate steam (trillion KJ) | Percentage of the total energy used by this industry |
|---|---|---|
| Pulp and paper | 2318 | 83 % |
| Chemicals | 1957 | 57 % |
| Petroleum refining | 1449 | 42 % |

**Table 3.5: Use of steam in several industries**

**Achieved environmental benefits**

Steam itself is non-toxic.

**Cross-media effects**

- generation of steam has the usual emissions from combustion
- where boiler water is treated, there are emissions of chemicals, from the treatment or deionisers
- waste steam or hot condensate can raise temperatures in receiving sewers or waters.

**Operational data**

A steam system is made up of four distinct components: the generation plant (the boiler), the distribution system (steam network, i.e. steam and condensate return), the consumer or end user (i.e. plant/process using the steam/heat) and the condensate recovery system. An efficient heat production, distribution, operation and maintenance contribute significantly to the reduction of heat losses.

- generation (see Combustion, Section 3.1): Steam is generated in a boiler or a heat recovery system generator by transferring the heat of combustion gases to water. When water absorbs enough heat, it changes phase from liquid to steam. In some boilers, a superheater further increases the energy content of the steam. Under pressure, the steam then flows from the boiler or steam generator and into the distribution system.

- distribution: The distribution system carries steam from the boiler or generator to the points of end-use. Many distribution systems have several take-off lines that operate at different pressures. These distribution lines are separated by various types of isolation valves, pressure-regulation valves, and sometimes backpressure turbines. Effective distribution system performance requires proper steam pressure balance, good condensate drainage, adequate insulation and effective pressure regulation.

  In the case of a higher pressure operation, the following benefits are possible:

    - the saturated steam has a higher temperature
    - the volume is smaller, which means the distribution pipes required are smaller
    - it is possible to distribute the steam at high pressure and to reduce its pressure prior to application. The steam thus becomes dryer and reliability is higher
    - a higher pressure enables a more stable boiling process in the boiler

  At a lower pressure, the following benefits arise:

    - there is less loss of energy at boiler level and in the distribution system
    - the amount of remaining energy in the condensate is relatively smaller (see Section 3.2.11)
    - leakage losses in the pipe system are lower
    - there is a decrease in scale build-up

  Due to the high operating pressure values in steam systems, safety is an extremely important aspect in steam processes. In addition, a steam system is often subject to water hammer or various types of corrosion. As a result, the reliability and lifespan of the different components also strongly depends on the design, the set-up and maintenance of the installation.

- end-use: There are many different end uses of steam, e.g.:

    - mechanical drive: turbines, pumps, compressors, etc. This is usually for large-scale equipment, such as power generation, large compressors, etc.
    - heating: process heating, drying all types of paper products, space heating
    - use in chemical reactions: moderation of chemical reactions, fractionation of hydrocarbon components and as a source of hydrogen in steam methane reforming.

  Common steam system end-use equipment includes heat exchangers, turbines, fractionating towers, strippers and chemical reaction vessels.

  Power generation is discussed in the LCP BREF, co- and tri-generation are discussed in Section 3.4 and 3.4.2 respectively.

In process heating, the steam transfers its latent heat to a process fluid in a heat exchanger. The steam is held in the heat exchanger by a steam trap until it condenses, at which point the trap passes the condensate into the condensate return system. In a turbine, the steam transforms its energy to mechanical work to drive rotating machinery such as pumps, compressors or electrical generators. In fractionating towers, steam facilitates the separation of various components of a process fluid. In stripping applications, steam is used to extract contaminants from a process fluid. Steam is also used as a source of water for certain chemical reactions.

- recovery of condensate: When steam transfers its latent heat to an application, water condenses in the steam system and is returned to the boiler via the condensate return system. First, the condensate is returned to a collection tank from where it is pumped to the deaerator, which strips out oxygen and non-condensable gases. Makeup water and chemicals can be added either in the collection tank or in the deaerator. The boiler feed pumps increase the feed-water pressure to above boiler pressure and inject it into the boiler to complete the cycle.

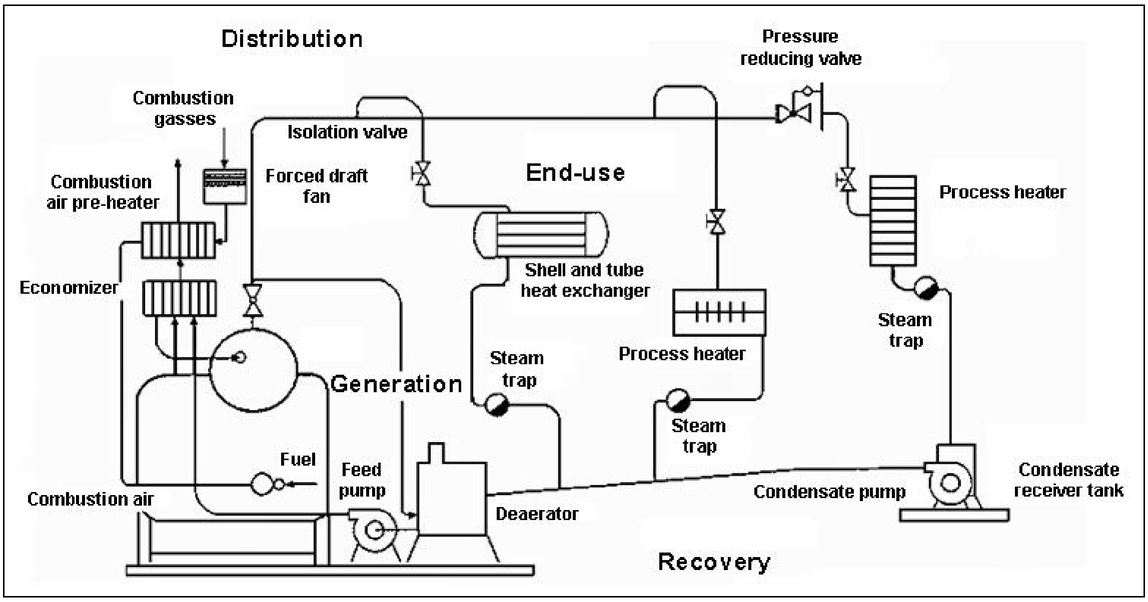


**Figure 3.3: Typical steam generation and distribution system**
**[123, US_DOE]**

## Applicability

- widely used

## Economics

The cost of steam generation is directly influenced by the price of the fuel used (see Combustion, Section 3.1); a price advantage in favour of a particular fuel may well outweigh a relatively smaller thermal efficiency penalty associated with that fuel. Nonetheless, for any particular fuel, significant savings can be achieved by improving thermal efficiency.

Eliminating avoidable energy losses associated with steam generation and its distribution (including the return of condensate) can significantly reduce the steam cost at the point of use.

Potential energy savings for the individual sites may range from less than 1 to 35 %, with an average saving of 7 %.

**Driving force for implementation**

- The reduction of energy costs, emissions and the rapid return of investment
- Use of steam: ease and flexibility of use, low toxicity, high heat delivery for system size.

**Examples**

Widely used in many IPPC sectors, such as: power generation, all chemical sectors, pulp and paper, food, drink and milk.

**Reference information**

[32, ADENE, 2005], [33, ADENE, 2005, 123, US_DOE, , 125, EIPPCB]

## 3.2.2 Overview of measures to improve steam system performance

Common performance opportunities for the generation, distribution and recovery areas of the system are listed in Table 3.5.

*Note: titles in this table and the titles in this section need to be the same. We could also consider changing the order in the section, but this depends on the order of explanations and time.*

| Techniques | Benefits | Section |
|---|---|---|
| **DESIGN and CONTROL** | | |
| Development of an improvement strategy by analysing and benchmarking the system performance, and improving the system operation and management | Optimise energy savings | Section 2.2.2, 2.6 |
| Design for new systems and significant rebuilds, e.g. replacing boiler(s) | Optimise energy savings | Section 2.2.3 |
| Energy efficient design and installation of steam distribution pipework. | Optimise energy savings | |
| Improving operating procedures and boiler controls | Optimise energy savings | Section 2.7.5 |
| Using sequential boiler controls (apply only to sites with more than one boiler) | | |
| Installing flue-gas isolation dampers (applicable only to sites with more than one boiler) | | |
| **GENERATION** | | |
| Minimise excess air | Reduces waste gas flow and therefore the amount of heat lost up the stack, allowing more of the fuel energy to be transferred to steam | Section 3.1.2 |
| Clean boiler heat transfer surfaces.<br>Prevention and removal of scale deposits on heat transfer surfaces | Promotes effective heat transfer from the combustion gases to the steam | Section 3.2.5 |
| Install heat recovery equipment (feed-water economisers and/or combustion air preheaters) | Recovers available heat from exhaust gases and transfers it back into the system by preheating feed-water or combustion air | Sections 3.2.4 and 3.1.1 |
| Improve water treatment to minimise boiler blowdown. Installing automatic total dissolved solids control | Reduces the amount of total dissolved solids in the boiler water, which allows less blowdown and therefore less energy loss | Section 3.2.6 |
| Recover energy from boiler blowdown | Transfers the available energy in a blowdown stream back into the system, thereby reducing energy loss | Section 3.2.7 |
| Add/restore boiler refractory | Reduces heat loss from the boiler and restores boiler efficiency | |
| Optimise deaerator vent rate | Minimises avoidable loss of steam | Section 3.2.14 |
| Minimise boiler short cycling losses | Optimise energy savings | Section 3.2.13 |
| Carrying out boiler maintenance | | Section 2.6 |
| **DISTRIBUTION** | | |
| Planned maintenance programme to cover the issues below | | Section 2.6 |
| Repair steam leaks | Minimises avoidable loss of steam | Section |
| Minimised venting in the system | Minimises avoidable loss of steam | Section 3.2.10 |
| Ensure that steam system piping, valves, fittings and vessels are well insulated | Reduces energy loss from piping and equipment surfaces | Section 3.2.8 |

| | | |
|---|---|---|
| Implement an effective steam trap maintenance programme | Reduces passage of live steam into the condensate system and promotes efficient operation of end-use heat transfer equipment | Section 3.2.10 |
| Isolate steam from unused lines | Minimises avoidable loss of steam and reduces energy loss from piping and equipment surfaces | Section 3.2.15 |
| Utilise backpressure turbines instead of PRVs | Provides a more efficient method of reducing steam pressure for low-pressure services | Section 3.2.9 |
| **RECOVERY** | | |
| Optimise condensate recovery | Recovers the thermal energy in the condensate and reduces the amount of makeup water added to the system, saving energy and chemicals treatment | Section 3.2.11 |
| Use high-pressure condensate to make low-pressure steam (flash steam) | Exploits the available energy in the returning condensate | Section 3.2.12 |

**Table 3.6: Common energy efficiency techniques for industrial steam systems**
**Adapted and combined from [123, US_DOE]**

In most cases, steam is generated in an industrial installation by means of a combustion reaction, so some overlap of energy efficiency comprehensive measures applicable to both combustion and steam sections cannot be avoided: these are noted in Table 3.5. The techniques specific to steam are discussed in this section.

To implement any of these measures, it is crucial to have relevant, quantified information and knowledge of fuel usage, steam generation and the steam network. Metering and monitoring steam contributes to the understanding of the process operation, together with a knowledge of how far the operating parameters can be modified and is thus essential to the successful integration of, e.g. heat recovery into a process (see Section 2.7)

### 3.2.3 Operating and control techniques

**Description**

*Improving operating procedures and boiler controls*
A modern control system optimising boiler usage is shown in Figure 3.4 below. This type of control is discussed further in Sections 2.7.4 and 2.7.5.

*Using sequential boiler controls*
Where a site has more than one boiler, the steam demand should be analysed and the boilers used to optimise energy usage, by reducing short cycling, etc. *(no data supplied)*

*Installing flue-gas isolation dampers* (apply only to sites with more than one boiler) *(no data supplied)*

**Achieved environmental benefits**
Energy savings.

**Cross-media effects**

**Operational data**

### Applicability

The installation of more than one boiler may be considered to cope with varying demands over the working cycle. The boilers may be of different types, depending on the demand curve, cycle times, etc.

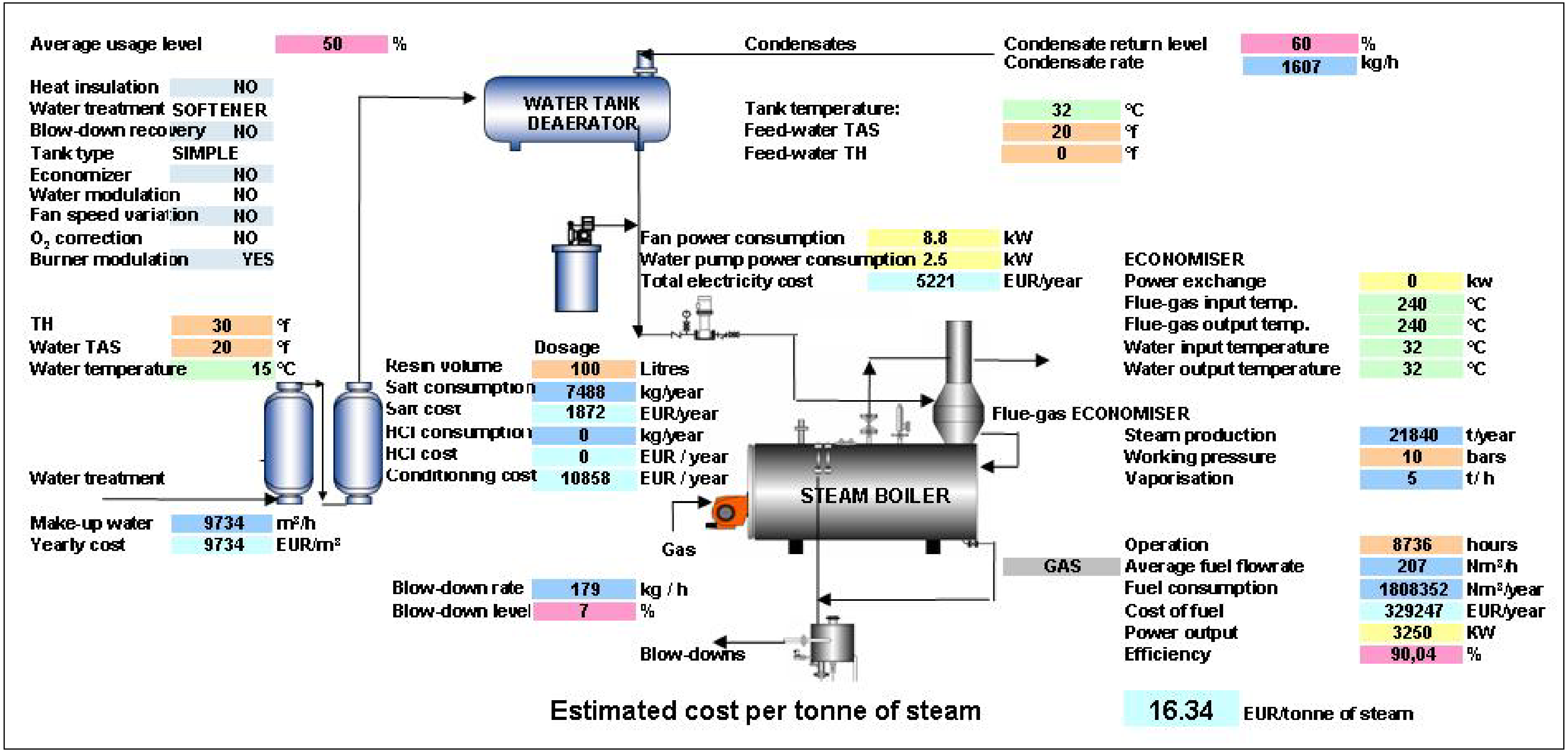
### Economics

### Driving force for implementation

### Examples

### Reference information

[123, US_DOE, , 134, Amalfi, 2006, 179, Stijns, 2005]



Average usage level 50 %

Heat insulation NO
Water treatment SOFTENER
Blow-down recovery NO
Tank type SIMPLE
Economizer NO
Water modulation NO
Fan speed variation NO
$O_2$ correction NO
Burner modulation YES

TH 30 °f
Water TAS 20 °f
Water temperature 15 °C

Make-up water 9734 m$^3$/h
Yearly cost 9734 EUR/m$^3$

Condensate return level 60 %
Condensate rate 1607 kg/h

Tank temperature: 32 °C
Feed-water TAS 20 °f
Feed-water TH 0 °f

Fan power consumption 8.8 kW
Water pump power consumption 2.5 kW
Total electricity cost 5221 EUR/year

Resin volume 100 Litres
Salt consumption 7488 kg/year
Salt cost 1872 EUR/year
HCl consumption 0 kg/year
HCl cost 0 EUR / year
Conditioning cost 10858 EUR / year

Blow-down rate 179 kg / h
Blow-down level 7 %

ECONOMISER
Power exchange 0 kw
Flue-gas input temp. 240 °C
Flue-gas output temp. 240 °C
Water input temperature 32 °C
Water output temperature 32 °C

Steam production 21840 t/year
Working pressure 10 bars
Vaporisation 5 t/ h

GAS
Operation 8736 hours
Average fuel flowrate 207 Nm$^3$/h
Fuel consumption 1808352 Nm$^3$/year
Cost of fuel 329247 EUR/year
Power output 3250 KW
Efficiency 90,04 %

Estimated cost per tonne of steam 16.34 EUR/tonne of steam

**Figure 3.4: Modern control system optimising boiler usage**

*TWG: TH, TAS in the figure, what do thay stand for?*

### 3.2.4 Preheating feed-water (including the use of economisers)

**Description**

The water leaving the deaerator generally has a temperature of approximately 105°C. The water in the boiler at a higher pressure is at a higher temperature. Heat recovery is possible by preheating the feed-water, thus reducing the steam boiler fuel requirements.

The preheating can be done in three ways:

- using waste heat (e.g. from a process)
- using economisers
- using deaerated feed-water.

Feed-water can be preheated by available waste heat, e.g. using water/water-heat exchangers, or by the hot flue-gas of the steam boiler. An economiser [(1) in Figure 3.5] is a heat exchanger which reduces steam boiler fuel requirements by transferring heat from the flue-gas to the incoming feed-water.

In addition, the condensate can be preheated with deaerated feed-water before reaching the feed-water container [(2) in Figure 3.5]. The feed-water from the condensate tank [(3) in Figure 3.5] has a lower temperature than the deaerated feed-water from the feed-water container [(2) in Figure 3.5]. Through a heat exchanger, the deaerated feed-water is cooled down further (the heat is transmitted to the feed-water from the condensate tank). As a result, the deaerated feed-water forwarded through the feed-water pump is cooler when it runs through the economiser [(1) in Fig. 1]. It thus increases its efficiency due to the larger difference in temperature and reduces the flue-gas temperature and flue-gas losses. Overall, this saves live steam, as the feed-water in the feed-water container is warmer and therefore less live steam is necessary for its deaeration.

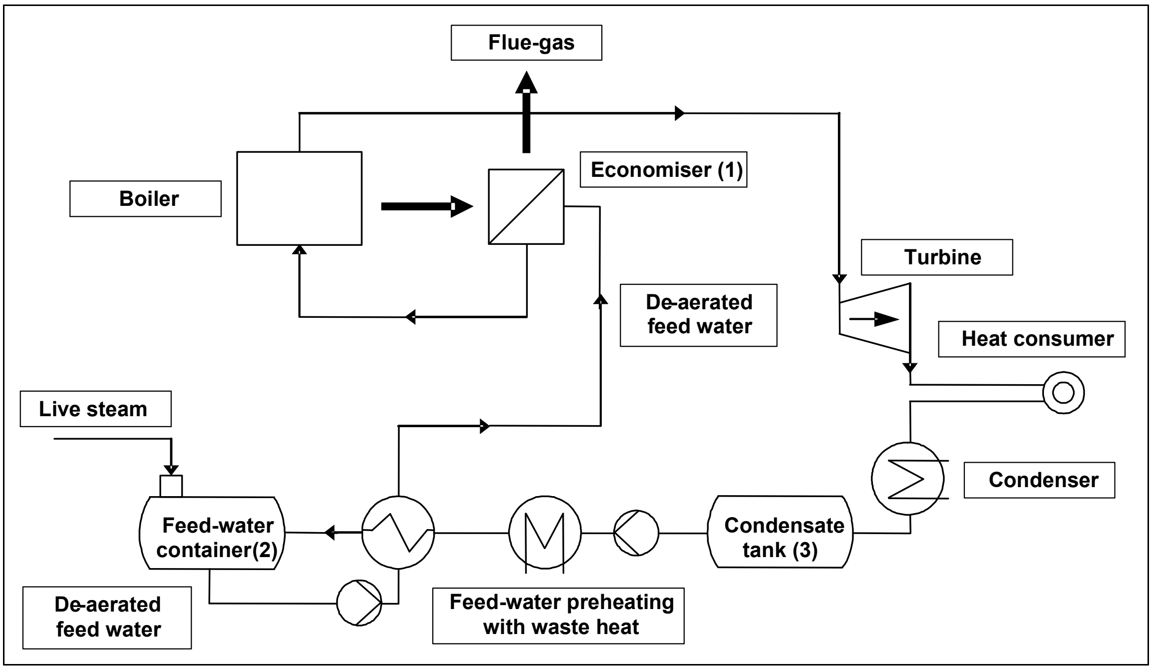


Figure 3.5: Feed-water preheating

Overall efficiency can be increased through these measures, that is, less fuel energy input is required for a certain steam output.

### Achieved environmental benefits

The energy recovery which can be achieved depends on the temperature of the flue-gases (or that of the main process), the choice of surface and, to a large extent, on the steam pressure.

It is widely accepted that an economiser can increase production efficiency by 4 %. The water supply needs to be controlled in order to achieve a continuous use of the economiser.

### Cross-media effects

Possible disadvantages of these three possibilities are that more space is required and their availability for industrial facilities decreases with rising complexity.

### Operational data

According to the manufacturer's specifications, economisers are commonly available with a rated output of 0.5 MW. Economisers designed with ribbed tubes are used for rated outputs of up to 2 MW, and equipped with finned tubes for outputs over 2 MW. In the case of outputs over 2 MW, around 80 % of the large water tube boilers delivered are equipped with economisers, as they are even economical when operated in single shifts (at system loads of 60 –70 %).

The exhaust gas temperature typically exceeds the saturated steam temperature by around 70 ºC. The exhaust gas temperature for a standard industrial steam generator is about 180°C. The lower limit of the flue-gas temperature is the flue-gases' acid dew point. The temperature depends on the fuel used and/or the fuel's sulphur content (and is around 160 C for heavy fuel oil, 130°C for light fuel oil and 100°C for natural gas). In boilers using heating oil, corrosion will occur more easily and part of the economiser has to be designed to be replaced. If the temperature of the exhaust gas drops significantly below the dew point, economisers might lead to corrosion, which usually occurs when there is a significant sulphur content in the fuel.

Unless special steps are taken, soot builds up in chimneys below this temperature. As a consequence, economisers are frequently equipped with a bypass controller. This controller diverts a proportion of the exhaust gases around the economiser if the temperature of the gases in the chimney drops too low. Working on the principle that a 20 ºC reduction in the temperature of the exhaust gas increases efficiency by around 1 %, this means that, depending on the steam temperature and drop in temperature caused by the heat exchanger, efficiency can improve by up to 6 – 7 %. The temperature of the feed-water to be heated in the economiser is typically increased from 103 to around 140 C.

### Applicability

In some existing plants, feed-water preheating systems can only be integrated with difficulty. In practice, feed-water preheating with deaerated feed-water is applied only rarely.

In high output plants, feed-water preheating through an economiser is standard. In this context, however, it is possible to improve the efficiency of the economiser up to 1 % by increasing the temperature difference. Using waste heat from other processes, it is also feasible in most of installations. There is also potential to use it in lower output plants (see Economics, below).

### Economics

The amount of energy saving potential by implementing economiser feed-water preheating depends on several conditions such as local system requirements, condition of the chimney or flue-gas quality. The payback for a particular steam distribution system will depend on its operating hours, the actual fuel price and location.

In practice, the possible savings from feed-water preheating amount to several per cent of the steam volume generated. Therefore, even in small boilers the energy savings can be in the range of several GWh per year. For example, with a 15 MW boiler savings of roughly 5 GWh/yr, some EUR 60000/yr and about 1000 tonnes $CO_2$/yr can be attained. The savings are proportional to the size of the plant, which means that larger plants will see higher savings.

Boiler flue-gases are often rejected to the stack at temperatures of more than 100 to 150 ºC higher than the temperature of the generated steam. Generally, boiler efficiency can be increased by 1 % for every 40 ºC reduction in the flue-gas temperature. By recovering waste heat, an economiser can often reduce fuel requirements by 5 to 10 % and pay for itself in less than 2 years. Table 3.7 shows examples of the potential for heat recovery.

| **Recoverable heat from boiler flue-gases** | | | | |
|---|---|---|---|---|
| Initial stack gas Temperature, ºF | Recoverable heat, MMBtu/h (1 Btu = 1055.1 J) | | | |
| | **Boiler thermal output MMBtu/h** | | | |
| | **25** | **50** | **100** | **200** |
| 400 | 1.3 | 2.6 | 5.3 | 10.6 |
| 500 | 2.3 | 4.6 | 9.2 | 18.4 |
| 600 | 3.3 | 6.5 | 13.0 | 26.1 |

**Table 3.7: Based on natural gas fuel, 15 % excess air and a final stack temperature of 250 ºF**
*TWG See note at start on Imperial units*

**Driving force for implementation**
Reduction of energy cost and minimisation of $CO_2$ emissions.

**Examples**
Widely used.

**Reference information**
[29, Maes, 2005], [16, CIPEC, 2002, 26, Neisecke, 2003, 28, Berger, 2005, 123, US_DOE]

### 3.2.5 Prevention and removal of scale deposits on heat transfer surfaces

**Description**
On generating boilers as well as in heat exchange tubes, a scale deposit might occur on heat transfer surfaces. This deposit occurs when soluble matter reacts in the boiler water to form a layer of material on the waterside of the boiler exchange tubes.

Scale creates a problem because it typically possesses a thermal conductivity an order of magnitude less than the corresponding value for bare steel. When a deposit of a certain thickness and given composition is formed on the heat exchange surface, the heat transfer through surfaces is reduced as a function of the scale thickness. Even small deposits might thus serve as an effective heat insulator and consequently reduce heat transfer. The result is overheating of boiler tube metal, tube failures and loss of energy efficiency. By removing the deposit, operators can easily save on energy use and on the annual operating costs.

Fuel waste due to boiler scale may be 2 % for water-tube boilers and up to 5 % in fire-tube boilers.

At boiler level, a regular removal of this scale deposit can produce substantial energy savings.

### Achieved environmental benefits

Reduced energy losses.

Energy losses as a function of scale thickness and composition are given in Table 3.7.

'Normal' scale is usually encountered in low pressure applications. The high iron and iron plus silica scale composition results from high pressure service conditions.

| Energy loss due to scale deposits | | | |
|---|---|---|---|
| Scale thickness, inches | Fuel loss, % of total use | | |
| | **Scale type** | | |
| | **'Normal'** | **High iron** | **Iron plus silica** |
| 1/64 | 1.0 | 1.6 | 3.5 |
| 1/32 | 2.0 | 3.1 | 7.0 |
| 3/64 | 3.0 | 4.7 | - |
| 1/16 | 3.9 | 6.2 | - |

**Table 3.8: Energy loss due to scale deposits**
**[National Institute of Standards and Technology, Handbook 115, Supplement 1, US]**

### Cross-media effects

By treating feed-water to prevent scale deposits, the use of chemicals may increase.

### Operational data

Removing the deposit will require the boiler to be out of use.

There are different ways of removing and preventing deposit formation:

- if pressure is reduced, the temperature will also reduce, which curtails scale deposits. This is one reason why steam pressure should be kept as low as possible (see Section 3.2.1)
- the deposit can be removed during maintenance, both mechanically as well as with acid cleaning
- if scale formation returns too rapidly, the treatment of feed-water needs to be reviewed. A better purification or extra additives may be required.

An indirect indicator of scale or deposit formation is flue-gas temperature. If the flue-gas temperature rises (with boiler load and excess air held constant), the effect is likely to be due to the presence of scale.

### Applicability

Whether scale deposits need to be removed can be ascertained by a simple visual inspection during maintenance. As a rule of thumb, maintenance several times per year may be effective for appliances at high pressure (50 bar). For appliances at low pressure (2 bar) annual maintenance is recommended.

It is possible to avoid deposits by improving the water quality (e.g. by switching to soft water or demin water). An acid treatment for deposit removal has to be carefully assessed, particularly for high pressure steam boilers.

### Economics

Depends on method used, and other factors, such as raw feed-water chemistry, boiler type, etc. Payback in fuel saving, increased reliability of the steam system and increased operating life of the boiler system (giving savings on lost production time and capital costs).

See examples, Annex 10.

**Driving force for implementation**
Increased reliability of the steam system and increased operating life of the boiler system.

**Examples**
Widely used.

**Reference information**
[16, CIPEC, 2002, 29, Maes, 2005, 123, US_DOE]

### 3.2.6 Minimising blowdown from the boiler

**Description**
Minimising the blowdown rate can substantially reduce energy losses as the temperature of the blowdown is directly related to that of the steam generated in the boiler.

As water vaporises in the boiler during steam generation, dissolved solids are left behind in the water, which in turn raises the concentration of dissolved solids in the boiler. The suspended solids may form sediments, which degrade heat transfer (see Section 3.2.5). Dissolved solids promote foaming and carryover of boiler water into the steam.

In order to reduce the levels of suspended and total dissolved solids (TDS) to acceptable limits, two procedures are used, automatically or manually in either case:

- bottom blowdown is carried out to allow a good thermal exchange in the boiler. It is usually a manual procedure done for a few seconds every several hours
- surface or skimming blowdown is designed to remove the dissolved solids that concentrate near the liquid surface and it is often a continuous process.

The blowdown of salt residues to drain causes further losses accounting for between one and three per cent of the steam employed. On top of this, further costs may also be incurred for cooling the blowdown residue to the temperature prescribed by regulatory authorities.

In order to reduce the required amount of blowdown there are several possibilities:

- the recovery of condensate (see Section 3.2.11). This condensate is already purified and thus does not contain any impurities, which will be concentrated inside the boiler. If half of the condensate can be recovered, the blowdown can be reduced by 50 %
- depending on the quality of the feed-water, softeners, decarbonation, demineralisation might be required. Additionally, deaeration of the water and addition of conditioning products are necessary. The level of blowdown is linked with the level of the more concentrated component present or added to the feed-water. In case of direct feed of the boiler, blowdown, rates of 7 to 8 % are possible; this can be reduced to 3 % or less when water is pretreated
- the installation of automated blowdown control systems can also be considered, usually by monitoring conductivity. This can lead to an optimisation between reliability and energy loss. The blowdown rate will be controlled by the most concentrated component knowing the maximum concentration possible in the boiler (TAC max. of the boiler 38 ºC; Silica 130 mg/l; Chloride <600 mg/l). For more details, see EN 12953 – 10.

Pressure degasification caused by vaporisation also results in further losses of between one and three per cent. $CO_2$ and oxygen are removed from the fresh water in the process (by applying slight excess pressure at a temperature of 103°C). This can be minimised by optimising the deaerator vent rate (see Section 3.2.14).

### Achieved environmental benefits

The amount of energy depends on the pressure in the boiler. The energy content of the blowdown is represented in Table 3.9below. This immediately indicates that savings can be achieved by reducing blowdown frequency.

| **Energy content of blowdown in kJ/kg of steam produced** | | | | | |
|---|---|---|---|---|---|
| **Blowdown frequency (% of boiler output)** | **Boiler operating pressure** | | | | |
| | **2 barg** | **5 barg** | **10 barg** | **20 barg** | **50 barg** |
| 1 % | 4.8 | 5.9 | 7.0 | 8.4 | 10.8 |
| 2 % | 9.6 | 11.7 | 14.0 | 16.7 | 21.5 |
| 4 % | 19.1 | 23.5 | 27.9 | 33.5 | 43.1 |
| 6 % | 28.7 | 35.2 | 41.9 | 50.2 | 64.6 |
| 8 % | 38.3 | 47.0 | 55.8 | 66.9 | 86.1 |
| 10 % | 47.8 | 58.7 | 69.8 | 83.6 | 107.7 |

**Table 3.9: Energy content of blowdown**

The amount of waste water will also be reduced if blowdown frequency is reduced. The energy or cooling water used for any cooling of this waste water will also be saved.

### Cross-media effects

Discharges of treatment chemicals, chemicals used in deioniser regeneration, etc.

### Operational data

The optimum blowdown frequency is determined by various factors including the quality of feed-water and the associated water treatment, the proportion of condensates re-used, the type of boiler (flowrate, working pressure, type of fuel, etc.). Blowdown rates typically range between 4 and 8 % of the amount of fresh water, but this can be as high as 10 % if make-up water has a high content of solids. Blowdown rates for optimised boiler houses should be lower than 4 %. Blowdown rates should be driven by the antifoaming and oxygen scavenger additives in the treated water rather than by dissolved salts.

### Applicability

If blowdown is reduced below a critical level, the problems of foaming and scaling may return. The other measures in the description (recovery of condensate, water pretreatment may also be used to lower this critical value.

Insufficient blowdown may lead to a degradation of the installation. Excessive blowdown will result in a waste of energy.

A condensate return is usually standard in all cases except where steam is injected into the process. In this case, a reduction of blowdown by condensate return is not feasible.

### Economics

Significant savings in energy, chemicals, feed-water and cooling can be achieved, and makes this viable in all cases, see examples detailed in Annex 10.

USD 714 = USD 32721 = 37128.11 EUR (USD 1 = EUR 1.1347, conversion date 1st January 2002)

**Driving force for implementation**

- economics
- plant reliability.

**Examples**

Widely used.

**Reference information**

[29, Maes, 2005], [16, CIPEC, 2002] [123, US_DOE, , 133, AENOR, 2004]

### 3.2.7 Recovering energy from boiler blowdown

**Description**

Energy can be recovered from boiler blowdown by using a heat exchanger to preheat boiler make-up water. Any boiler with continuous blowdown exceeding 4 % of the steam rate is a good candidate for the introduction of blowdown waste heat recovery. Larger energy savings occur with high pressure boilers.

**Achieved environmental benefits**

The potential energy gains from the recovery of heat from the blowdown is shown in Table 3.9:

| Recovered energy from blowdown losses, in MJ/h[11] | | | | | |
|---|---|---|---|---|---|
| Blowdown rate<br>% of boiler output | Operating pressure of the boiler | | | | |
| | 2 barg | 5 barg | 10 barg | 20 barg | 50 barg |
| 1 % | 42 | 52 | 61 | 74 | 95 |
| 2 % | 84 | 103 | 123 | 147 | 190 |
| 4 % | 168 | 207 | 246 | 294 | 379 |
| 6 % | 252 | 310 | 368 | 442 | 569 |
| 8 % | 337 | 413 | 491 | 589 | 758 |
| 10 % | 421 | 516 | 614 | 736 | 948 |

**Table 3.10: Recovered energy from blowdown losses**

By reducing the blowdown temperature, it is easier to comply with environmental regulations requiring waste water to be discharged below a certain temperature.

**Cross-media effects**

None known.

**Operational data**

See examples, Annex 10.

**Applicability**

See Economics, below.

---

[11] These quantities have been determined based on a boiler output of 10 t/h, an average temperature of the boiler water of 20 °C, and a recovery efficiency of 88 % of the heat from blowdown.

**Economics**

The efficiency of such a technique usually results in cost recovery within a few years.

**Driving force for implementation**

Cost savings.

**Examples**

See examples, Annex 10.

**Reference information**

[29, Maes, 2005], [16, CIPEC, 2002] [123, US_DOE]

### 3.2.8 Insulation on steam pipes and condensate return pipes

**Description**

Steam pipes and condensate return pipes that are not insulated are a constant source of heat loss which is easy to remedy. Insulating all heat surfaces is, in most cases, an easy measure to implement. In addition, localised damage to insulation can be readily repaired. Insulation might have been removed or not replaced during operation maintenance or repairs. Removable insulation covers for valves or other installations may be absent.

Wet or hardened insulation needs to be replaced. The cause of wet insulation can often be found in leaking pipes or tubes. The leaks should be repaired before the insulation is replaced.

**Achieved environmental benefits**

Table 3.11 shows heat losses from uninsulated steam line at different steam pressures.

| Heat loss per 100 feet of uninsulated steam line | | | | |
|---|---|---|---|---|
| Distribution line diameter (inches) | Heat loss per 100 feet of uninsulated steam line (MMBtu/yr) | | | |
| | Steam pressure (psig) | | | |
| | 15 | 150 | 300 | 600 |
| 1 | 140 | 285 | 375 | 495 |
| 2 | 235 | 480 | 630 | 840 |
| 4 | 415 | 850 | 1120 | 1500 |
| 8 | 740 | 1540 | 2030 | 2725 |
| 12 | 1055 | 2200 | 2910 | 3920 |

**Table 3.11: Heat loss per 100 feet of uninsulated steam line**

A reduction of energy losses through better insulation can also lead to a reduction in the use of water and the related savings on water treatment.

**Cross-media effects**

Increased use of insulating materials.

**Operational data**

**Applicability**

Any high temperature piping or equipment that should be insulated to reduce heat loss, reduce emissions, and improve safety. As a general rule, any surface that reaches temperatures greater than 50°C should be insulated to protect personnel.

**Economics**

See Example

**Driving force for implementation**

Easy to achieve compared to other techniques. Rapid payback.

**Examples**

Widely applied.

**Reference information**

[29, Maes, 2005], [16, CIPEC, 2002]

### 3.2.8.1 Installation of removable insulating pads or valves and fittings

**Description**

During maintenance operations, the insulation that covers pipes, valves, and fittings is often damaged or removed and not replaced.

The insulation of the different components in an installation often varies. In a modern boiler, the boiler itself is generally well insulated. On the other hand, the fittings, valves and other connections are usually not as well insulated. Re-usable and removable insulating pads are available for surfaces that emit heat.

**Achieved environmental benefits**

The efficiency of this technique depends on the specific application, but the heat loss as a result of frequent breaches in insulation is often underestimated.

The table below summarises energy savings due to the use of insulating valve covers for a range of valves sizes and operating temperatures. These values were calculated using a computer program that meets the requirements of ASTM C 680-heat loss and surface temperature calculations. The energy savings are defined as the energy loss between the un-insulated valve and the insulated valve operating at the same temperature.

| **Energy savings from installing removable insulated valve covers (Btu/h)** | | | | | | |
|---|---|---|---|---|---|---|
| **Operating temperature °F** | **Valve Size (inches)** | | | | | |
| | **3** | **4** | **6** | **8** | **10** | **12** |
| 200 | 800 | 1090 | 1560 | 2200 | 2900 | 3300 |
| 300 | 1710 | 2300 | 3300 | 4800 | 6200 | 7200 |
| 400 | 2900 | 3400 | 5800 | 8300 | 10800 | 12500 |
| 500 | 4500 | 6200 | 9000 | 13000 | 16900 | 19700 |
| 600 | 6700 | 9100 | 13300 | 19200 | 25200 | 29300 |

**Table 3.12: Energy savings from installing removable insulated valve covers (Btu/h)**

Proper installation of insulating covers may also reduce the noise.

**Cross-media effects**
None known.

**Operational data**
Re-usable insulating pads are commonly used in industrial facilities for insulating flanges, valves, expansion joints, heat exchangers, pumps, turbines, tanks and other irregular surfaces. The pads are flexible and vibration resistant and can be used with equipment that it is horizontally or vertically mounted or equipment that it is difficult to access.

**Applicability**
Any high temperature piping or equipment that should be insulated to reduce heat loss, reduce emissions, and improve safety. As a general rule, any surface that reaches temperatures greater than 50°C should be insulated to protect personnel. Insulating pads can be easily removed for periodic inspection or maintenance, and replaced as needed. Insulating pads can also contain material to act as acoustic barriers to help control noise.

Special care must be taken when insulating steam traps. Different types of steam traps can only operate correctly if limited quantities of steam can condense or if a defined quantity of heat can be emitted (for instance certain thermostatic and thermodynamic steam traps).

If these steam traps are over-insulated, this might impede their operation. It is therefore necessary to consult with the manufacturer or other expert before insulating.

**Economics**
Using Table 3.2.8.1, the annual fuel and cost savings from installing a 1-inch thick insulating pad on an uninsulated 6-inch (150 mm) gate valve in a 250 lb/psig saturated steam line (406 ºF) can be calculated. Assuming continuous operation with natural gas at a boiler efficiency of 80 % and a fuel price of USD 4.5/MMBtu:

annual fuel savings = 5992 Btu/h x 8760 h/year x 1/0.80 = 65.6 MMBtu/year

Annual Cost Savings = 65.6 MMBtu/year x USD 4.5/MMBtu = USD 295 per 6-inch gate valve = EUR 334.73 (USD 1 =EUR 1.1347, conversion date 1st January 2002).

**Driving force for implementation**
- cost saving
- health and safety.

**Examples**
Widely used.

**Reference information**
[29, Maes, 2005], [16, CIPEC, 2002, 123, US_DOE]

### 3.2.9 Utilising backpressure turbines instead of pressure-reducing valves

**Description**

Throttling devices are very common in industry and are used to control and reduce pressure mainly through valves. Since the throttling process is isenthalpic (where the enthalpy up and down flows are equal) no energy is lost and according to the first law of thermodynamics, its efficiency is optimal. However, this has an inherent typical mechanical irreversibility which reduces pressure and increases the entropy of the fluid without giving any additional benefit. Consequently, exergy is lost and the fluid (after the pressure drop) is less capable of producing energy, e.g. in a turbine expansion process.

Therefore, if the aim is to reduce the pressure of a fluid, it is desirable to use isentropic expansions and provide useful work in addition through turbines. If this is not possible, the working pressure should always be as low as possible, to avoid large pressure changes, with associated exergy losses through valves or using compressors or pumps to input additional energy.

A regular practice in industrial installations is to keep the pressure at the inlet of a turbine at the design conditions. This usually implies the use (and abuse) of inlet valves to control the turbine. According to the second law of thermodynamics, it is better to have variation of the pressure specifications (sliding pressure) and to keep the admission valves completely open.

As a general recommendation, valves should be sized as large as possible. A satisfactory throttling process can be achieved with a pressure drop of 5 – 10 % at maximum flow, instead of 25 – 50 % as has been past practice with valves of too small a size. The pump driving the fluid must be also sized to take account of the variable conditions.

However, a better alternative is to use a backpressure turbine, which retains the isenthalpic conditions and is completely reversible (in thermodynamic terms). The turbine is used to generate electricity.

**Achieved environmental benefits**

Reduces energy lost as entropy.

**Cross-media effects**

None known.

**Operational data**

(See example in Annex 1)

**Applicability**

*TWG to advise.*

**Economics**

*TWG to advise.*

**Driving force for implementation**

**Examples**

**Reference information**

[6, Cefic, 2005, 123, US_DOE]

## 3.2.10 Implementing a control and repair programme for steam traps

**Description**

Leaking steam traps lose significant quantities of steam, which result in large energy losses. Proper maintenance can reduce these losses in an efficient manner. In steam systems where the steam traps have not been inspected in the last three to five years, up to about 30 % of all steam traps may have failed allowing steam to escape. In systems with a regularly scheduled maintenance programme, less than 5 % of the total number of traps should be leaking.

There are many different types of steam traps and each type has its own characteristics and preconditions. Checks for escaping steam are based on acoustic, visual, electrical conductivity or thermal checks.

When replacing steam traps, changing to orifice venturi steam traps can be considered. Measurements have shown that under several conditions, these traps result in lower steam losses and longer lifespan.

**Achieved environmental benefits**

| Leaking steam trap discharge rate | | | | |
|---|---|---|---|---|
| Trap orifice diameter (inches) | Steam Loss (lb/h) | | | |
| | Steam pressure (psig) | | | |
| | 15 | 100 | 150 | 300 |
| 1/32 | 0.85 | 3.3 | 4.8 | - |
| 1/16 | 3.4 | 13.2 | 18.9 | 36.2 |
| 1/8 | 13.7 | 52.8 | 75.8 | 145 |
| 3/16 | 30.7 | 119 | 170 | 326 |
| 1/4 | 54.7 | 211 | 303 | 579 |
| 3/8 | 123 | 475 | 682 | 1303 |

**Table 3.13: Leaking steam trap discharge rate**

**Operational data**

An annual survey checks all steam traps. The different categories of functioning are shown in included in Table 3.14.

| Abbreviation | Description | Definition |
|---|---|---|
| **OK** | All right | Works as it should |
| **BT** | Blow through | Steam is escaping from this steam trap, with maximum steam losses. Needs to be replaced |
| **LK** | Leaks | Steam leaks from this steam trap. It needs to be repaired or replaced |
| **RC** | Rapid cycle | The cycle of this thermodynamic steam trap is too fast. Must be repaired or replaced |
| **PL** | Plugged | The steam trap is closed. No condensate can flow through it. To be replaced |
| **FL** | Flooded | This steam trap can no longer deal with the flow of condensate. To be replaced with a trap of the right size |
| **OS** | Out of service | This line of out of order |
| **NT** | Not tested | The steam trap cannot be reached and was therefore not tested |

**Table 3.14: Various operating phases of steam traps**

The amount of steam lost can be estimated for a steam trap as follows:

$$L_{t,y} = \frac{1}{150} \times FT_{t,y} \times FS_{t,y} \times CV_{t,y} \times h_{t,y} \times \sqrt{P_{in,t}^2 - P_{out,t}^2}$$

Where:

- $L_{t,y}$ is the amount of steam that steam trap t is losing in period y (tonne)
- $FT_{t,y}$ is the operating factor of the steam trap t during period y
- $FS_{t,y}$ is the load factor of steam trap t during period y
- $CV_{t,y}$ is the flow coefficient of steam trap t during period y
- $h_{t,y}$ is the amount of operating hours of steam trap t during period y
- $P_{in,t}$ is the ingoing pressure of steam trap t (atm)
- $P_{out,t}$ is the outgoing pressure of steam trap t (atm).

The operating factor $FT_{t,y}$ follows from Table 3.15.

| | **Type** | **FT** |
|---|---|---|
| **BT** | Blow through | 1 |
| **LK** | Leaks | 0.25 |
| **RC** | Rapid cycle | 0.20 |

**Table 3.15: Operating factors for steam losses in steam traps**

The load factor takes into account the interaction between steam and condensate. The more condensate that flows through the steam trap, the less space there is to let steam through. The amount of condensate depends on the application as shown in Table 3.16 below:

| **Application** | **Load factor** |
|---|---|
| Standard process application | 0.9 |
| Drip and tracer steam traps | 1.4 |
| Steam flow (no condensate) | 2.1 |

**Table 3.16: Load factor for steam losses**

Finally the size of the pipe also determines the flow coefficient:

- $CV = 3.43 D^2$
- where D = the radius of the opening (cm).

An example calculation is:

- $FT_{t,y} = 0.25$
- $FS_{t,y} = 0.9$ because the amount steam that passed through the trap is condensed, but correct in comparison with the capacity of the steam trap (Table 3.15 above)
- $CV_{t,y} = 7.72$
- D = 1.5 cm
- $h_{t,y} = 6000$ hours per year
- $P_{in,t} = 16$ atm
- $P_{out,t} = 1$ atm.

The steam trap thus loses up to 1110 tonnes of steam per year.

If this occurs in an installation where steam costs EUR 15/tonne, then the final loss would amount to: EUR 16 650 per year.

If the steam totally escapes, rather than just by leaking, costs might rise to up to EUR 66 570 per year.

These losses rapidly justify the setting up of an effective management and control system for all the steam traps in an installation.

**Applicability**

A programme to track down leaking steam traps and to determine whether steam traps need to be replaced is required for every steam system. Steam traps often have a relatively short lifespan. The costs for replacement are generally considerably less than the losses as a result of defective operation. Steam traps should be checked at least yearly.

An automated control mechanism can be installed on each type of steam trap. Automatic steam trap controls are particularly applicable for:

- traps with high operating pressures, so any leakage rapidly accrues high energy losses
- traps whose operation is critical to operations and blockage will result in damage or production loss.

**Economics**

Rapid payback, depending on the scale of the leakage. See example above.

**Driving force for implementation**

- cost
- improved steam system efficiency.

**Examples**

Wisely used.

**Reference information**

[29, Maes, 2005], [16, CIPEC, 2002]

## 3.2.11 Collecting and returning condensate to the boiler for re-use

**Description**

Re-using condensate has four objectives:

- re-using the energy contained in the hot condensate
- saving the cost of the (raw) top-up water
- saving the cost of boiler water treatment (the condensate has to be treated)
- saving the cost of waste water discharge (where applicable).

Condensate is typically collected at atmospheric pressure. The condensate may originate from steam in appliances at a much higher pressure. Where this condensate is returned to atmospheric pressure, flash steam is spontaneously created. This can also be recovered.

**Achieved environmental benefits**

At a pressure of 1 bar the condensate has a temperature of 100 ºC and enthalpy of 419 kJ/kg. If the flash steam is recovered, then the total energy content will depend on the operating load of the installation. The energy component which leaves the steam system via the condensate is shown in Table 3.17.

| Absolute pressure (bar) | In condensate at atmospheric pressure (%) | In condensate + flash steam (%) |
|---|---|---|
| 1 | 13.6 | 13.6 |
| 2 | 13.4 | 16.7 |
| 3 | 13.3 | 18.7 |
| 5 | 13.2 | 21.5 |
| 8 | 13.1 | 24.3 |
| 10 | 13.0 | 25.8 |
| 15 | 13.0 | 28.7 |
| 20 | 12.9 | 30.9 |
| 25 | 12.9 | 32.8 |
| 40 | 12.9 | 37.4 |
| Note: The feed-water for the installation often has an average annual temperature of approximately 15°C. These figures were calculated based on a situation where the supply of water to the installation is at 15°C, or with an enthalpy of 63 kJ/kg | | |

**Table 3.17: Percentage of total energy present in the condensate at atmospheric pressure and flash steam**

The re-use of condensate also results in a reduction in costs for water treatment and the use of chemicals to do so. The quantity of water to be discharged is also reduced.

**Cross-media effects**

**Operational data**

**Applicability**

The technique is not applicable in cases where the recovered condensate is polluted or if the condensate is not recoverable because the steam has been injected in the process.

**Economics**

Recovery of condensate has significant benefits and should be considered in all applicable cases (see Applicability, above)

**Driving force for implementation**

**Examples**

**Reference information**

[29, Maes, 2005], [16, CIPEC, 2002]

### 3.2.12 Re-using of flash steam

**Description**

Flash steam is formed when the condensate at high pressure is expanded. Once the condensate is at a lower pressure, part of the condensate will vaporise again and form flash steam.

Flash steam contains both the purified water and a large part of the available energy, which is still present in the condensate.

The energy recovery can be achieved through heat exchange with make-up water. If the blowdown water is brought to a lower pressure in a flash tank beforehand, then steam will be formed at a lower pressure. This flash steam can be moved directly to the degasser and can thus be mixed with the fresh make-up water. The flash steam does not contain any dissolved salts and the steam represents a large portion of the energy in the blowdown.

Flash steam does however occupy a much larger volume than condensate. The return pipes must be able to deal with this without pressure increases. Otherwise, the resulting backpressure may hamper the proper functioning of steam traps and other components upstream.

In the boiler house the flash steam, like the condensate, can be used to heat the fresh feed-water in the degasser. Other possibilities include the use of the flash steam for air heating.

Outside the boiler house, flash steam can be used to heat components under 100 C. In practice, there are steam uses at the pressure of 1 barg. Flash steam can thus be injected into these pipes. Flash steam can also be used to preheat air, etc.

Low pressure process steam requirements are usually met by throttling high pressure steam, but a portion of the process requirements can be achieved at low cost by flashing high pressure condensate. Flashing is particularly attractive when it is not economically feasible to return the high pressure condensate to the boiler.

**Achieved environmental benefits**

The benefits are case-dependant.

It is usually more energy efficient to recover pressurised condensate. This also has a positive effect on the amount of blowdown required and thus on the amount of waste water to be discharged.

At a pressure of 1 bar the condensate has a temperature of 100 C and an enthalpy of 419 kJ/kg. If the flash steam or the steam post evaporation is recovered, then total energy content depends on the workload of the installation. The energy component which leaves the steam systems via the condensate is shown in Table 3.18, which also shows the relative quantity of energy in the condensate and in the flash steam. At higher pressures the flash steam contains the majority of the energy.

| **Absolute pressure (bar)** | **In condensate at atmospheric pressure (%)** | **In condensate + steam post evaporation at boiler pressure (%)** | **Relative share of the energy which can be recovered in flash steam (%)** |
|---|---|---|---|
| 1 | 13.6 | 13.6 | 0.0 |
| 2 | 13.4 | 16.7 | 19.9 |
| 3 | 13.3 | 18.7 | 28.9 |
| 5 | 13.2 | 21.5 | 38.6 |
| 8 | 13.1 | 24.3 | 46.2 |
| 10 | 13.0 | 25.8 | 49.4 |
| 15 | 13.0 | 28.7 | 54.7 |
| 20 | 12.9 | 30.9 | 58.2 |
| 25 | 12.9 | 32.8 | 60.6 |
| 40 | 12.9 | 37.4 | 65.4 |
| Note: The feed-water for the installation often has an annual average temperature of approximately 15°C. These figures were calculated based on a situation whereby the supply of water to the installation occurs at 15°C, or with an enthalpy of 63 kJ/kg | | | |

**Table 3.18: Percentage of total energy present in the condensate at atmospheric pressure and flash steam**

## Cross-media effects

The return of the pressurised condensate is always more energy efficient. *TWG: Is this true?*

## Operational data

The re-use of flash steam is possible in many cases, often for heating of under 100°C. There are a number of possibilities.

*Collection of the flash steam in the condensate pipes.* During the lifespan of the installation, various components may be added into the same lines, and the condensate return pipe may become too small for the quantity of condensate to be recovered. In most cases, this condensate is recovered at atmospheric pressure, therefore the major part of the pipe is filled with flash steam. If there is an increase in condensate discharge, the pressure in these pipes may rise to over 1 barg. This can lead to problems upstream and may hamper the proper functioning of steam traps, etc.

*Flash steam can be discharged to a flash tank installed in the middle of the return pipe run.* The flash steam can then be used for local preheating or heating at less than 100°C. At the same time, the pressure in the condensate return pipe will be reduced to normal, avoiding the upgrading of the condensate return network.

When reviewing an existing network, an option to be considered is to return the condensate at a lower pressure. This will generate more flash steam and the temperature will also decrease to under 100 C.

When using steam, for example for heating at less than 100 C, it is possible that the real pressure in the heating coil, following adjustment, decreases to under 1 bar. This may result in suction of the condensate into the coil, and flooding it. This can be avoided by recovering condensate at low pressure. More flash steam is generated as a result of the low pressure and more energy is recovered from the condensate. The components working at these lower temperatures can be switched to an individual network. However, additional pumps need to be installed to maintain this low pressure and to remove any air leaking into the pipes from the outside.

**Applicability**

In theory, any energy use at a lower temperature can be a possible use for flash steam instead of fresh steam and there will be a range of opportunities on investigation, although implementation is not always easy.

**Economics**

The recovery of flash steam saves on fresh top-up water and its treatment, although the main cost savings are in energy. The recovery of flash steam leads to much greater energy savings than with the simple collection of liquid condensate. *TWG: Is this true?*

See Examples in Annex 10.

**Driving force for implementation**

- Cost saving
- Use of low pressure steam.

**Examples**

**Reference information**

[29, Maes, 2005, 123, US_DOE]

## 3.2.13 Minimising boiler short cycling losses

**Description**

Losses during short cycles occur every time a boiler is switched off for a short period of time. The boiler cycle consists of a purge period, a post-purge, an idle period, a pre-purge and a return to firing. Part of the losses during the purge periods and idle period can be low in modern, well isolated boilers, but can increase rapidly in older boilers with inferior insulation.

Losses due to short-term cycles for steam boilers can be magnified if the boilers can generate the required capacity in a very short period of time. This is the case if the installed capacity of the boiler is considerably larger than that generally needed. The steam demand for the process can change over time and should be reassessed periodically (see Section 2.2.2). Total steam demand may have been reduced through energy saving measures. Alternatively, boilers may have been installed with a view to a later expansion, which was never realised.

A first point for attention is the type of boiler in the design phase of the installation. Fire tube boilers have considerably large thermal inertia, and considerable water content. They are equipped to deal with continuous steam demand and to meet large peak loads. Steam generators or water tube boilers in contrast can also deliver steam in larger capacities. Their relatively lower water content makes water pipe boilers more suitable for installations with strongly varying loads.

Short cycling can be avoided by installing multiple boilers with a smaller capacity instead of one boiler with a large capacity. As a result, both flexibility and reliability are increased. An automated control of the generation efficiency and of the marginal costs for steam generation in each boiler can direct a boiler management system. Thus additional steam demand is provided by the boiler with the lowest marginal cost.

Another option is possible where there is a standby boiler. In this case, the boiler can be kept to temperature by circulating water from the other boiler directly through the standby boiler. This minimises the flue-gas losses for standby. The standby boiler should be well insulated and with a correct air valve for the burner.

Energy savings can be obtained by boiler isolation or boiler replacement. Replacing large boilers with several smaller boilers can be considered.

**Achieved environmental benefits**

**Cross-media effects**
None known.

**Operational data**
Maintaining a boiler on standby at the right temperature will cost a quantity of energy throughout the year, which coincides with approximately 8 % of the total capacity of the boiler. The benefits of reliability and energy saving measures have to be determined.

**Applicability**
The negative impact of short cycling becomes clear when there is low usage of available boiler capacity for instance, less than 25 %. In such cases, it is good practice to review whether to replace the boiler system.

**Economics**
See example in Annex 10.

**Driving force for implementation**
- cost saving
- better system performance.

**Examples**

**Reference information**
[29, Maes, 2005, 123, US_DOE]

## 3.2.14 Optimising deaerator vent rate

**Description**

Deaerators are mechanical devices that remove dissolved gases from boiler feed-water. Deaeration protects the steam system from the effects of corrosive gases. It accomplishes this by reducing the concentration of dissolved oxygen and carbon dioxide to a level where corrosion is minimised. A dissolved oxygen level of 5 parts per billion (ppb) or lower is needed to prevent corrosion in most high pressure (>200 psig) boilers. While oxygen concentrations of up to 43 ppb may be tolerated in low pressure boilers, equipment life is extended at little or no cost by limiting the oxygen concentration to 5 ppb. Dissolved carbon dioxide is essentially completely removed by the deaerator.

The design of an effective deaeration system depends upon the amount of gases to be removed and the final gas ($O_2$) concentration desired. This in turn depends upon the ratio of boiler feed-water makeup to returned condensate and the operating pressure of the deaerator.

Deaerators use steam to heat the water to the full saturation temperature corresponding to the steam pressure in the deaerator and to scrub out and carry away dissolved gases. Steam flow may be parallel, cross, or counter to the water flow. The deaerator consists of a deaeration section, a storage tank, and a vent. In the deaeration section, steam bubbles through the water, both heating and agitating it. Steam is cooled by incoming water and condensed at the vent condenser. Non-condensable gases and some steam are released through the vent. However, this should be optimised to provide satisfactory stripping, with minimised steam loss (See Operational data, below).

Sudden increases in free or 'flash' steam can cause a spike in deaerator vessel pressure, resulting in re-oxygenation of the feed-water. A dedicated pressure-regulating valve should be provided to maintain the deaerator at a constant pressure.

**Achieved environmental benefits**

Saving of unnecessary energy loss in steam venting.

**Cross-media effects**

None reported.

**Operational data**

Steam provided to the deaerator provides physical stripping action and heats the mixture of returned condensate and boiler feed-water makeup to saturation temperature. Most of the steam will condense, but a small fraction (usually 5 to 14 %) must be vented to accommodate the stripping requirements. Normal design practice is to calculate the steam required for heating, and then make sure that the flow is sufficient for stripping as well. If the condensate return rate is high (>80 %) and the condensate pressure is high compared to the deaerator pressure, then very little steam is needed for heating, and provisions may be made for condensing the surplus flash steam.

Deaerator steam requirements should be re-examined following the retrofit of any steam distribution system, condensate return, or heat recovery energy conservation measures.

Continuous dissolved oxygen monitoring devices can be installed to aid in identifying operating practices that result in poor oxygen removal.

The deaerator is designed to remove oxygen that is dissolved in the entering water, not entrained air. Sources of 'free air' include loose piping connections on the suction side of pumps and improper pump packing.

**Applicability**
All sites with deaerators on steam systems. Optimisation is an ongoing maintenance measure.

**Economics**

**Driving force for implementation**
Cost saving in unnecessary venting of steam.

**Examples**
Widely used.

**Reference information**
http://www1.eere.energy.gov/industry/bestpractices/pdfs/steamsourcebook.pdf

### 3.2.15 Optimising steam distribution systems

**Description**
The distribution system transports steam from the boiler to the various end-uses. Although distribution systems may appear to be passive, in reality, these systems regulate the delivery of steam and respond to changing temperature and pressure requirements. Consequently, proper performance of the distribution system requires careful design practices and effective maintenance. The piping should be properly sized, supported, insulated, and configured with adequate flexibility. Pressure-regulating devices such as pressure reducing valves and backpressure turbines should be configured to provide a proper steam balance among the different steam headers. Additionally, the distribution system should be configured to allow adequate condensate drainage, which requires adequate drip leg capacity and proper steam trap selection.

Maintenance of the system is important, especially:

- to ensure that traps operate correctly (see Section 3.2.10)
- that insulation is installed and maintained (see Section 3.2.8)
- that leaks are detected and dealt with systematically by planned maintenance. This is assisted by leaks being reported by operators and dealt with promptly. Leaks include air leaks on the suction side of pumps
- checking for and eliminating unused steam lines.

**Achieved environmental benefits**
Saving in energy from unnecessary losses.

**Cross-media effects**

### Operational data

Steam piping transports steam from the boiler to the end-uses. Important characteristics of well-designed steam system piping are that it is adequately sized, configured, and supported. The installation of larger pipe diameters may be more expensive, but can create less pressure drop for a given flowrate. Additionally, larger pipe diameters help to reduce the noise associated with steam flow. As such, consideration should be given to the type of environment in which the steam piping will be located when selecting the pipe diameter. Important configuration issues are flexibility and drainage. With respect to flexibility, piping (especially at equipment connections), needs to accommodate thermal reactions during system startups and shutdowns. Additionally, piping should be equipped with a sufficient number of appropriately sized drip legs to promote effective condensate drainage. Additionally, the piping should be pitched properly to promote the drainage of condensate to these drip lines. Typically, these drainage points experience two different operating conditions, normal operation and startup; both load conditions should be considered at the initial design stage.

### Applicability

All steam systems. Adequate sizing, of paperwork, minimising the number of tight bends, etc. can best be dealt with at the design and installation stages (including significant repairs, changes and upgrading).

### Economics

- proper sizing in design has a good payback within the lifetime of the system
- maintenance measures (such as minimising leaks) also exhibit rapid payback.

### Driving force for implementation

- cost saving
- health and safety.

### Examples

Widely used.

### Reference information

[123, US_DOE]

## 3.3 Waste heat recovery

[16, CIPEC, 2002], [26, Neisecke, 2003] , [34, ADENE, 2005], [97, Kreith, 1997].

This section deals with different types of waste heat recovery including heat exchangers and heat pumps. Heat naturally flows from the higher temperature to a lower temperature parts of a system (see Section 1.2.2.2, second law of thermodynamics), and waste heat recovery makes use of this. Waste heat recovery is the process of recovering and re-using rejected low-grade (low quality or low exergy) heat to replace generated or purchased energy. Heat recovery opportunities arise in the processes and utility systems in almost every industrial sector, and therefore there is inevitable overlap, such as with Section 3.2, which discusses the heat recovery techniques widely used in steam systems. Heat recovery is the dominant feature of co- and tri-generation systems, see Sections 3.4 and 3.4.2.

Energy may be recovered from, e.g.

- hot flue-gases
- exhaust air
- cooling fluids from cooling systems (gases, cooling water or hydraulic oil)
- hot or cold product or waste product
- hot or cold water drained to a sewer
- superheat and condenser heat rejected from refrigeration.

Waste heat is rejected heat released from a process at a temperature that is higher than the temperature of the plant air. As it is often available at a temperature that is lower than the intended level, this temperature must be raised, ‘upgraded’ through suitable equipment, e.g. heat pump.

*Heat recovery technologies*
The most commonly used heat recovery techniques are the following:

- direct usage: heat exchangers make use of heat as it is
- heat pumps upgrade the heat so that it can perform more useful work than could be achieved at its present temperature (i.e. an input of high quality energy raises the energy quality of the waste heat)
- multistage operations such as multi-effect evaporation, steam flashing and combinations of the approaches already mentioned.

Heat exchangers and heat pumps have the widest range of applications, regardless of the industry type.

Before the introduction of heat recovery equipment, it is essential to evaluate the quality and quantity of waste heat, and then to identify possible uses. Heat recovery is often limited by the quality of the waste heat and the possibilities for use. The options are:

- using the heat in the process from where it originates (i.e. recirculation, often using heat exchangers, e.g. economisers, see Section 3.2.4)
- using the heat within another system or unit (this option may arise because the waste heat is at an insufficiently high temperature). This is of two types:
  - within the installation, in another unit or process
  - in another installation (such as in integrated chemical facilities), or in the wider community, such as district heating. See Co-generation Section 3.4).
- if the waste heat does not have a sufficiently high exergy, this can be raised using heat pumps, or a low energy use can be found, such as hot water, space heating in HVAC.

Where hot and cold streams are available, then pinch technology can be used to identify where heat can be transferred (see Section 2.9).

It is crucial to have relevant, quantified information and knowledge of the processes from which the heat arises and into which the heat recovery is to be incorporated. The prime reason for difficulty and failure of waste heat recovery is lack of understanding. Errors and omissions are likely to have a more profound effect than, for example, an ill-judged choice of the type of heat exchanger. Apart from thermodynamic errors, it is the physical properties of a waste heat source which can lead to problems with whichever heat exchanger is chosen, if not fully investigated at the outset.

In-depth understanding of the process operation, together with knowledge of how far the operating parameters can be modified, is essential to the successful integration of heat recovery into a process. Detailed measuring and recording of operating data provides an excellent start for planning. This also helps the process engineer to identify savings possible through low cost measures.

### 3.3.1 Heat exchangers

**Description**
Direct heat recovery is carried out by heat exchangers. A heat exchanger is a device in which energy is transferred from one fluid or gas to another across a solid surface. They are used to either heat up or cool down processes or systems. Heat transfer happens by both convection and conduction.

Discharge heat at relatively low temperatures (up to 400 – 500 C) can be found in many industrial sectors such as:

- chemicals including polymers
- food and drink
- paper and board
- textiles and fabrics.

In this range of temperatures, the following heat recovery equipment (heat exchangers) can be used depending on the type of fluids involved (i.e. gas-gas, gas-liquid, liquid-liquid) and specific application:

- rotating regenerator (adiabatic wheel)
- coil
- heat pipe/thermosyphon heat exchanger
- tubular recuperator
- economiser
- condensing economiser
- spray condenser (fluid heat exchanger)
- shell and tube heat exchanger
- plate heat exchanger
- plate and shell heat exchanger.

At higher temperatures (above 400 C, *TWG: should this be above 500 ºC*), in process industries such as iron, iron and steel, copper, aluminium, glass and ceramics, the following methods are available for recovering waste heat from gases:

- plate exchangers
- shell and tube heat exchangers
- radiation tubes with recuperators
- convection tubes with recuperators
- recuperative burner systems and self-recuperative burners
- static regenerators
- rotary regenerators
- compact ceramic regenerators
- impulse-fired regenerative burners
- radial plate recuperative burners
- integral bed regenerative burners. Fluidised beds are used for severely fouling environments, e.g. in pulp and paper mills.
- energy optimising furnace.

Dynamic or scrapped surface heat exchangers are used mainly for heating or cooling with high viscosity products, crystallisation processes, evaporation, and high fouling applications.

One of the widest use of heat exchanges is for air conditioning, see Section 3.10. These systems use coils (referring to their serpentine internal tubing).

*Efficiency*

Heat exchangers are designed for specific energy optimised applications. The subsequent operation of heat exchangers under different or variable operating conditions is only possible within certain limits. This will result in changes to the transferred energy, the heat transfer coefficient (U-value) and the pressure drop of the medium.

The heat transfer coefficient and hence transferred power are influenced by the thermal conductivity as well as the surface condition and thickness of the heat transfer material. Suitable mechanical design and choice of materials can increase the efficiency of the heat exchanger. Costs and mechanical stresses also play a major role in the choice of material and structural design.

The power transferred through the heat exchanger is heavily dependent on the heat exchanger surface. The heat exchanger surface area may be increased using ribs (e.g. ribbed tube heat exchangers, lamella heat exchangers). This is particularly useful in attaining low heat transfer coefficients (e.g. gas heat exchangers).

The accumulation of dirt on the heat exchanger surface will diminish the heat transfer. Dirt levels may be reduced by using appropriate materials (very smooth surfaces), structured shapes (e.g. spiral heat exchangers) or changing the operating conditions (e.g. high medium speeds). Furthermore, heat exchangers may be cleaned or fitted with automatic cleaning systems (dynamic or scrapped surface).

Higher flowrates will increase the heat transfer coefficient. However, increased flowrates will also result in higher pressure drops. High levels of flow turbulence improve heat transfer but result in an increased pressure drop. Turbulence may be generated by using stamped heat exchanger plates or fitting diverters.

The transferred power is also dependent on the physical state of the medium (e.g. temperature and pressure). If air is used as the primary medium, it may be humidified prior to entering the heat exchanger. This improves the heat transfer.

**Achieved environmental benefits**

Energy saving are made by using secondary energy flows.

**Cross-media effects**

**Applicability**

Heat recovery systems are widely used with good results in many industrial sectors and systems, see Description, above. See also Section 3.2.

Waste heat recovery is not applicable where there is no demand that matches the production curve. However, this is being applied for an increasing number of cases, and many of these can be found outside of the installation, see Co-generation, Section 3.4, and Chapter 5.

**Economics**

Payback time may be as short as six months or as long as 50 years or more. In the Austrian pulp and paper industry, the payback time of the complex and different systems was between one and about three years.

The cost-benefits and payback (amortisation) periods can be calculated, e.g. as shown in the ECM BREF.

In some cases, particularly where the heat is used outside the installation, it may be possible to use funding from policy initiatives, see Chapter 5.

**Driving force for implementation**

- reduction of energy costs, reduction of emissions and the often rapid return of investments
- improved process operation, e.g. reduction of surface contamination (in scrapped surface systems), improvement of existing equipment/flows, reduction in system pressure-drop (which increases the potential maximum plant throughput)
- savings in effluent charges.

**Examples**

- Industries cited in the Description, above
- In the Austrian pulp and paper industry
- Tait Paper at Inverure, Aberdeenshire, UK.

**Reference information**

[16, CIPEC, 2002], [26, Neisecke, 2003], [34, ADENE, 2005] [97, Kreith, 1997] [127, TWG]

### 3.3.1.1 Monitoring and maintenance of heat exchangers

**Description**

Condition monitoring of heat exchanger tubes may be carried out using eddy current inspection. This is often simulated through computational fluid dynamics (CFD). Infrared photography (see Section 2.7.1) may also be used on the exterior of heat exchanges, to reveal significant temperature variations or hot spots.

Fouling can be a serious problem. Often, cooling waters from rivers, estuaries or a sea is used, and biological debris can enter and build layers. Another problem is scale, which is chemical deposit layers, such as calcium carbonate or magnesium carbonate (see Section 3.2.5). The process being cooled can also deposit scale, such as silica scale in alumina refineries See Examples, below).

**Achieved environmental benefits**

Improved heat exchange for heat recovery.

**Cross-media effects**

Use of chemicals for removing scale.

**Operational data**

- plate heat exchangers need to be cleaned periodically, by disassembling, cleaning and re-assembly
- tube heat exchangers can be cleaned by acid cleaning, bullet cleaning or hydrodrillling (the last two may be proprietary techniques)
- the operation and cooling of cooling systems is discussed in the CV BREF.

**Applicability**

**Economics**

**Driving force for implementation**

Maintaining production capacity.

**Examples**

Acid cleaning: Eurallumina, Portovecompany, Italy. See Annex 11
Infra red: [162, SEI, 2006]

**Reference information**

### 3.3.2 Heat pumps

**Description**

The main purpose for heat pumps is to transform energy from a lower temperature level (low exergy) to a higher level. Heat pumps can transfer heat (not generate heat) from man-made heat sources such as industrial processes, or from natural or artificial heat sources in the surroundings, such as the air, ground or water, for use in domestic, commercial or industrial applications. Heat pumps can also be used for cooling. Heat is then transferred in the opposite direction, from the application that is cooled, to the surroundings. Sometimes the excess heat from cooling is used to meet a simultaneous heat demand elsewhere. Heat pumps are used in co- and tri-generation, systems are in operation that provide both cooling and heating simultaneously, and with varying seasonal demands (see Sections 3.4 and 3.4.2).

In order to transport heat from a heat source to a location where heat is required, external energy is needed to drive the heat pump. The drive can be an electric motor or a combustion engine, or a heat source for adsorption heat pumps.

*Compression heat pumps (closed cycle)*

The most widely used heat pump is probably the compressor driven pump. It is, for instance, installed in refrigerators, air conditioners, chillers, dehumidifiers, heat pumps for heating with energy from rock, soil, water and air. It is normally driven by an electrical motor but for large installations, steam turbine driven compressors can be used.

Compression heat pumps use a counter-clockwise Carnot process (cold steam process) consisting of the phases of evaporation, compression, condensation and expansion in a closed cycle.

In the evaporator, the circulating working fluid evaporates under low pressure and low temperature, e.g. due to waste heat. Subsequently the compressor increases the pressure and temperature. The working fluid is liquefied in a condenser and releases the usable heat in this process. The fluid is then forced to expand to a low pressure and as it evaporates, it absorbs heat from the heat source. Thus the energy at low temperature in the heat source (e.g. waste water, flue-gas) has been transformed to a higher temperature level to be used in another process or system.

Figure 3.6 shows the principle of a compression heat pump.

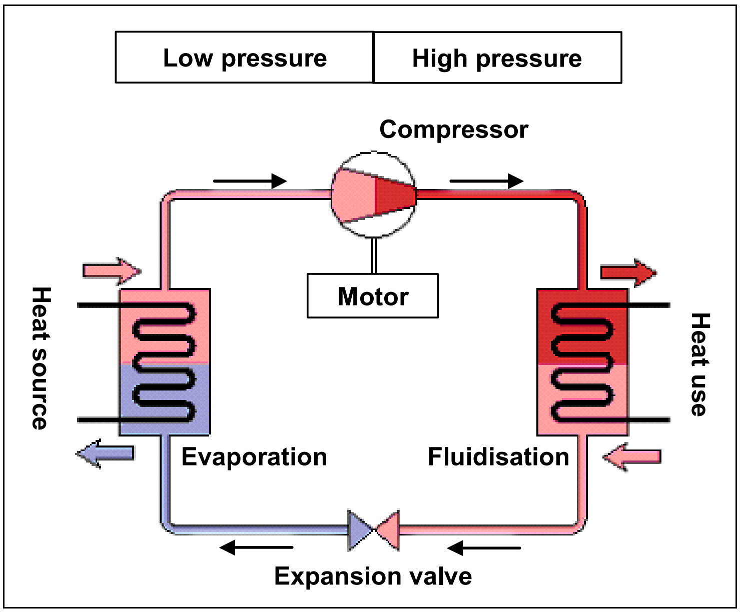


**Figure 3.6: Diagram of a compression heat pump**
**[28, Berger, 2005]**

In a compression heat pump, the degree of efficiency is indicated as the coefficient of performance (COP), which indicates the ratio of heat output to electrical energy input. The necessary energy input is effected in the form of electrical energy input to the compression motor.

The COP of the compression heat pump can be expressed as: COP = hC T1/(T1–T2) where hC is called the Carnot efficiency, T1 and T2 are the temperatures of the condenser and evaporator respectively. The Carnot efficiency can be regarded as a constant for moderate variations of the temperatures.

Modern compression heat pumps can reach a COP of up to 6, meaning that a heat output of 6 kW can be generated from an input of 1 kW of electrical energy in the compressor. At waste to energy (W-t-E) conditions, the ratio between output heat and compressor power (heat to power ratio) can be about 5.
*TWG; Is calculation of COP correct?*

*Absorption heat pumps*
The absorption heat pump is not as widely used, particularly in industrial applications. Like the compressor type it was originally developed for cooling. Commercial heat pumps operate with water in a closed loop through a generator, condenser, evaporator and absorber. Instead of compression, the circulation is maintained by water absorption in a salt solution, normally lithium bromide, in the absorber.

In an absorption heat pump, the gaseous working fluid (cooling agent) coming from the evaporator is absorbed by a liquid solvent, and heat is generated in the process. This enriched solution is conveyed to the ejector via a pump with an increase in pressure, after which the working fluid (cooling agent) is extracted from the two-substance mixture using an external heat supply (e.g. a natural gas burner, LPG, or waste heat). The absorber/ejector combination has a pressure increasing effect (thermal compressor).

The gaseous working substance exits the ejector at a higher pressure and enters the condenser, where it is liquefied and releases usable heat to the process. The energy input necessary to operate a solvent pump is low compared to that necessary to operate the compressor of a compression heat pump (the energy necessary to pump a liquid is lower than that necessary to compress and transport gas).

Figure 3.7 shows the principle of an absorption heat pump:

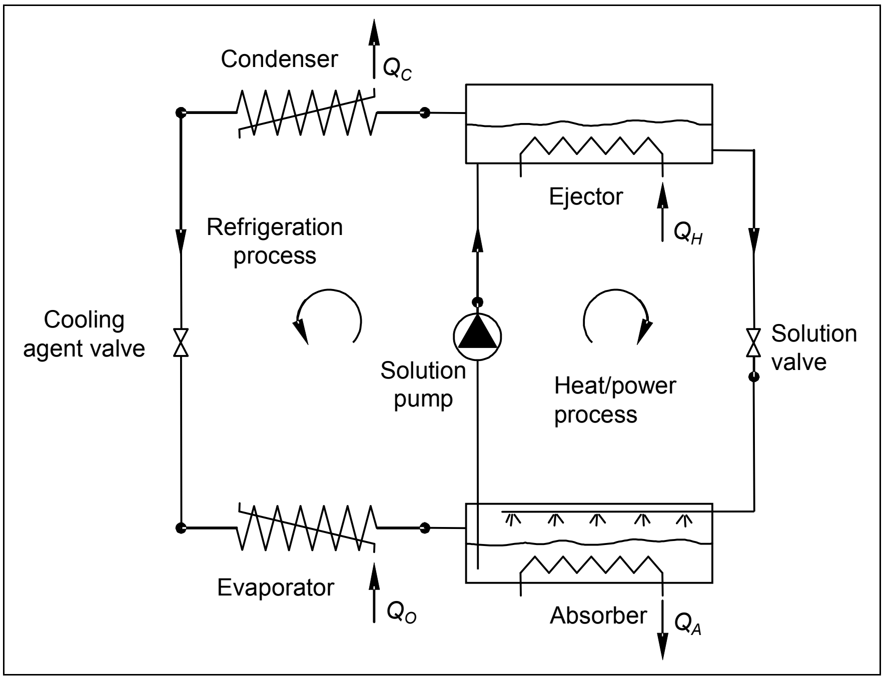


**Figure 3.7: Diagram of an absorption heat pump**
**[28, Berger, 2005]**

Where in Figure 3.7:

$Q_C$ = delivered heat output
$Q_H$ = primary energy input
$Q_O$ = waste heat input
$Q_A$ = delivered heat output

In absorption pumps, the degree of efficiency is indicated as the heat efficiency coefficient. It is defined as the ratio of heat output to fuel energy input. If waste heat is used as a heat source in the ejector, the thermal coefficient is used instead of heat efficiency. The thermal coefficient is defined as the ratio of heat output to waste heat input. The fuel input is supplied in the form of heat, for example from natural gas burners, steam or waste heat. Modern absorption heat pumps can reach heat efficiency coefficients of up to 1.5. The ratio between output heat and absorber power is normally about 1.6. Current systems with water/lithium bromide as working pair achieve an output temperature of 100 ºC and a temperature lift of 65 ºC. The new generation will have higher output temperatures (up to 260 ºC) and higher temperature lifts.

*Mechanical vapour recompression (MVR)*
MVR is an as open or semi-open heat pump (referring to the heat pump system). Low pressure vapour exhaust from industrial processes, such as boilers, evaporators or cookers, is compressed and subsequently condensed giving off heat at a higher temperature, and thereby replacing live steam or other primary energy. The energy to drive the compressor is typically only 5 to 10 % of the heat delivered. In Figure 3.8, a simplified flow sheet for a MVR installation in shown.

If the vapour is clean it can be used directly, but with contaminated vapours an intermediate heat exchanger (reboiler) is necessary. This is a semi-open system.

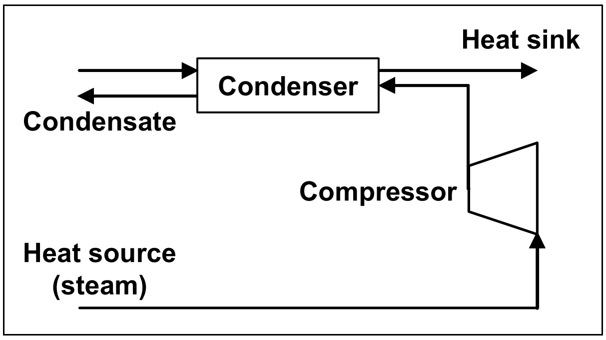


**Figure 3.8: Simple MVR installation**
**[18, Åsblad, 2005]**

### Achieved environmental benefits

Heat pumps enable the recovery of low grade heat, with primary energy consumption lower than the energy output (depending on the COP). This enables the use of low grade heat in useful applications, such as heating inside in the installation, or in the adjacent community. This results in reducing the use of primary energy and related gas emissions, such as carbon dioxide ($CO_2$), sulphur dioxide ($SO_2$) and nitrogen oxides ($NO_X$).

The efficiency of any other heat pump system is strongly dependent on the required temperature lift from source to sink.

In MVR, as one or two heat exchangers are eliminated (the evaporator and/or condenser in other heat pumps) efficiency is generally high. The efficiency is again expressed as 'coefficient of performance' (COP). It is defined as the ratio of heat delivered and shaft work to the compressor. In Figure 3.9 typical COP values for MVR installations are plotted versus temperature lift. Normal COP values for MVR installations are in the range 10 – 30.

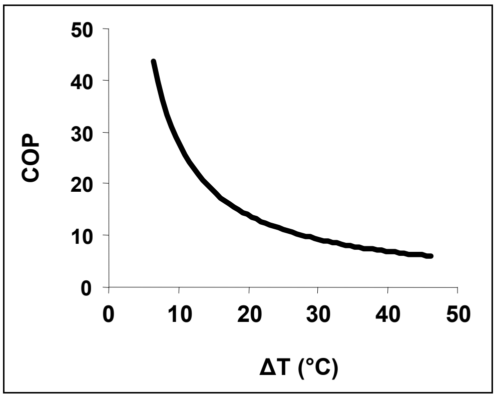


**Figure 3.9: COP versus temperature lift for a typical MVR system**
**[18, Åsblad, 2005]**

### Cross-media effects

Use of working fluids with environmental impacts when leaking or decommissioned.

### Operational data

See Descriptions of heat pumps above.

Compressor systems: currently applied working fluids limit the output temperature to 120°C.

Absorption systems: a water/lithium bromide working fluid pair can achieve an output of 100°C and a temperature lift of 65°C. New generation systems have higher output temperatures (up to 260°C) and higher temperature lifts.

Current MVR systems work with heat source temperatures of 70 – 80°C and delivery heat of 110 – 150°C, and in some cases, up to 200°C. The most common vapour compressed is steam although other process vapours are also used, notably in the petrochemical industry.

The COP for an MVR installation is given by Eq. 4.7:

**Eq 9**

$$\mathrm{COP} > \frac{\eta_{\mathrm{boiler}}}{\eta_{\mathrm{power\ plant}}\ \eta_{\mathrm{distribution}}}$$

In equation 9:

$\eta_{\mathrm{boiler}}$ is the boiler efficiency in the plant/industry
$\eta_{\mathrm{power}}$ is the efficiency of the power plant generating electricity for the national grid
$\eta_{\mathrm{distribution}}$ accounts for distribution losses in the electric network.

Thus the COP must be larger than, say, 3 to be energy efficient if the electricity is produced in a condensing power plant. In practice, all MVR installations will have COP values well above that.

In an industry with combined heat and power production, for example back-pressure turbines, it gets more complicated. In this case, the lost work from the back-pressure turbines must also be considered.

**Applicability**
Examples of applications for industrial heat pumps are:

- space heating
- heating and cooling of process flows
- water heating for washing, sanitation and cleaning
- steam production
- drying/dehumidification
- evaporation
- distillation
- concentration (dehydration).

They are also used in co- and tri-generation systems.

The most common waste heat streams in industry are cooling water, effluent, condensate, moisture, and condenser heat from refrigeration plants. Because of the fluctuation in waste heat supply, it may be necessary to use large (insulated) storage tanks to ensure stable operation of the heat pump.

Most MVR installations are in unit operations such as distillation, evaporation, and drying, but steam production to a steam distribution network is also common.

Relatively few heat pumps are currently installed in industry and usually realised in the course of planning new facilities and plants, or significant upgrades (see Section 2.2.3).

Heat pumps are more cost-effective when fuel costs are high. Systems tend to be more complex than fossil fuel fired systems, although the technology is robust.

### Economics

The economy depends strongly on the local situation. The amortisation period in industry is 2 years at best. This can be explained on the one hand by the low energy costs, which minimise savings through the use of heat pumps and on the other hand by the high investment costs involved.

The profitability for an MVR installation is, besides fuel and electricity prices, depends on installation costs. The installation cost for an installation at Nymölla in Sweden (see Examples below), was about EUR 4.5 million. The Swedish Energy Agency contributed a grant of nearly EUR 1.0 million. At the time of installation, the annual savings amounted to about EUR 1.0 million per year.

### Driving force for implementation

Saving of operational costs.
An installation could provide the means to increase production without investing in new boiler capacity if the boiler capacity is a limiting factor.

### Examples

- Dåvamyren, Umeå, Sweden: compressor driven heat pump in waste to energy plant
- Renova Göteborg, Sweden: absorption driven heat pump
- Borlänge, Halmstad and Tekniska Verken, Linköping, W-t-E plants, and bio-fuel burners, Sweden: MVR heat pumps
- at the StoraEnso sulphite mill in Nymölla, Sweden, a mechanical recompression system was installed in 1999. The heat source is exhaust steam from the pre-evaporation of black liquor. This contaminated steam, at 84 C, is first condensed in a steam/steam heat exchanger (reboiler) to produce clean steam at a temperature of approximately 5 C lower and at 0.45 barg pressure. The two-stage compressor raises the pressure to about 1.7 barg and the steam flow from the compressor, after de-superheating with water injection, amounts to 21 t/h. The steam is distributed in a low pressure steam system and used for pre-evaporation, feed-water heating, and district heating.

The mechanical compressor is driven by a back-pressure turbine. The shaft power is about 2 MW.

The operating experience has, after some initial problems, been very good. The MVR reduces the fuel oil consumption in the boilers by about 7000 – 7500 tonnes per year.

### Reference information

[21, RVF, 2002], [26, Neisecke, 2003], [28, Berger, 2005] [18, Åsblad, 2005], [114, Caddet Analysis Series No. 28, 2001], [115, Caddet Analysis Series No. 23], [116, IEA Heat Pump Centre]

## 3.4 Cogeneration

[65, Nuutila, 2005], [97, Kreith, 1997].

The Directive 2004/8/EC on the promotion of cogeneration, defines cogeneration as *'the simultaneous generation in one process of thermal energy and electrical and/or mechanical energy'*. It is also known as 'combined heat and power' (CHP). There is significant interest in cogeneration currently, supported at European Community level by the adoption of Directive 2003/96/EC on energy taxation, which sets out a favourable context for cogeneration (CHP). The Green Paper on energy efficiency highlights losses in electricity generation and transmission, and the recovery of the heat and localised cogeneration as ways of overcoming this.

This section deals with different cogeneration applications describing their suitability in different cases. Applications are now possible which are cost efficient on a small scale.

### 3.4.1 Different types of cogeneration

**Description**

| **Cogeneration technology** | **Default power to heat ratio, ºC** |
|---|---|
| Combined cycle gas turbines, (gas turbines combined with waste heat recovery boilers and one of the steam turbines mentioned below) | 0.95 |
| Steam turbine plants (back-pressure) | 0.45 |
| Steam condensing extraction turbine (back-pressure, uncontrolled extraction condensing turbines and extraction condensing turbines) | 0.45 |
| Gas turbines with heat recovery boilers | 0.55 |
| Internal combustion engines (Otto – or diesel (reciprocating) engines with heat utilisation) | 0.75 |
| Microturbines | |
| Stirling engines | |
| Fuel cells (with heat utilisation) | |
| Steam engines | |
| Organic Rankin cycles | |
| Other types | |

**Table 3.19: List of cogeneration technologies and default power to heat ratios [Dir 92/42/EEC]**

The amount of electricity produced compared to the amount of heat produced is usually expressed with the power to heat ratio which is under one if the amount of electricity produced is less than the amount of heat produced.

The annual load versus time curve can be used to determine the selection and size of a CHP.

*Back-pressure*
The simplest cogeneration power plant is the so-called back-pressure power plant, where CHP electricity and heat is generated in a steam turbine (see Figure 3.10). The electrical capacity of steam turbine plants working on the back-pressure process is usually a few dozen megawatts. The power to heat ratio is normally about 0.3 – 0.5. The power capacity of gas turbine plants is usually slightly smaller than that of steam turbine plants, but the power to heat ratio is often close to 0.5.

The amount of industrial back-pressure power depends on the heat consumption of a process and on the properties of high pressure, medium pressure and back pressure steam. The major determining factor of the back-pressure steam production is the power to heat ratio.

In a district heating power plant, the steam is condensed in the heat exchangers below the steam turbine and transmitted to consumers by circulating water. The steam from a back-pressure power plant again is fed to the factory where it surrenders its heat. The back-pressure is lower in a district heating power plant than in industrial back-pressure plants. This explains why the power to heat ratio of industrial back-pressure power plants is lower than that of district heating power plants.

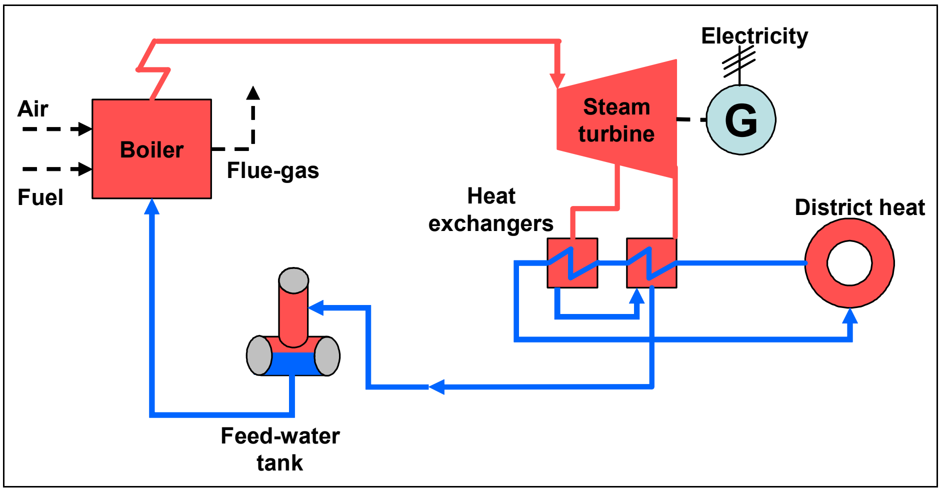


**Figure 3.10: Back-pressure plant**
**[65, Nuutila, 2005]**

*Extraction condensing*
A condensing power plant only generates electricity whereas in an extraction condensing power plant some of the steam is extracted from the turbine to generate heat (see Figure 3.11). The steam supply is explained in Section 3.2.

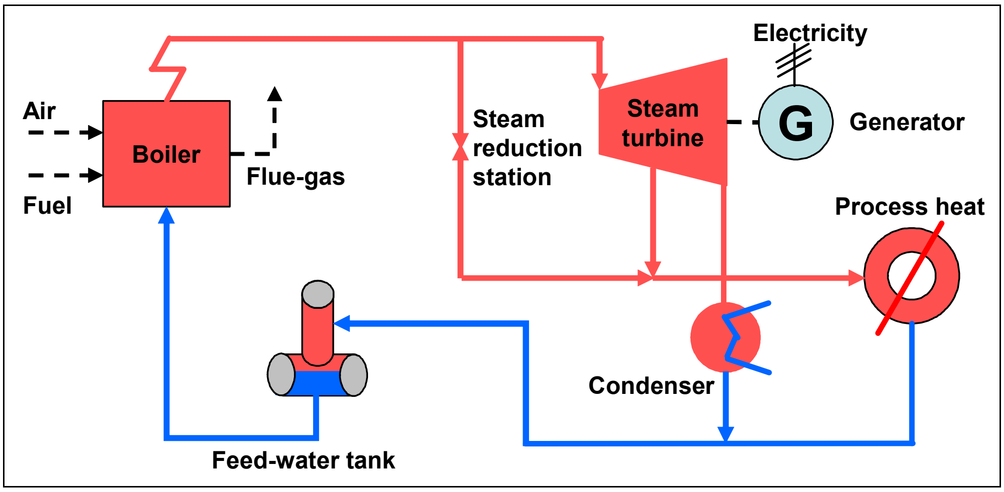


**Figure 3.11: Extraction condensing plant**
**[65, Nuutila, 2005]**

*Gas turbine heat recovery boiler*
In gas turbine heat recovery boiler power plants heat is generated with hot flue-gases of the turbine (see Figure 3.12). The fuel used in most cases is natural gas, oil, or a combination of these. Gas turbines can also be fired with gasified solid or liquid fuels.

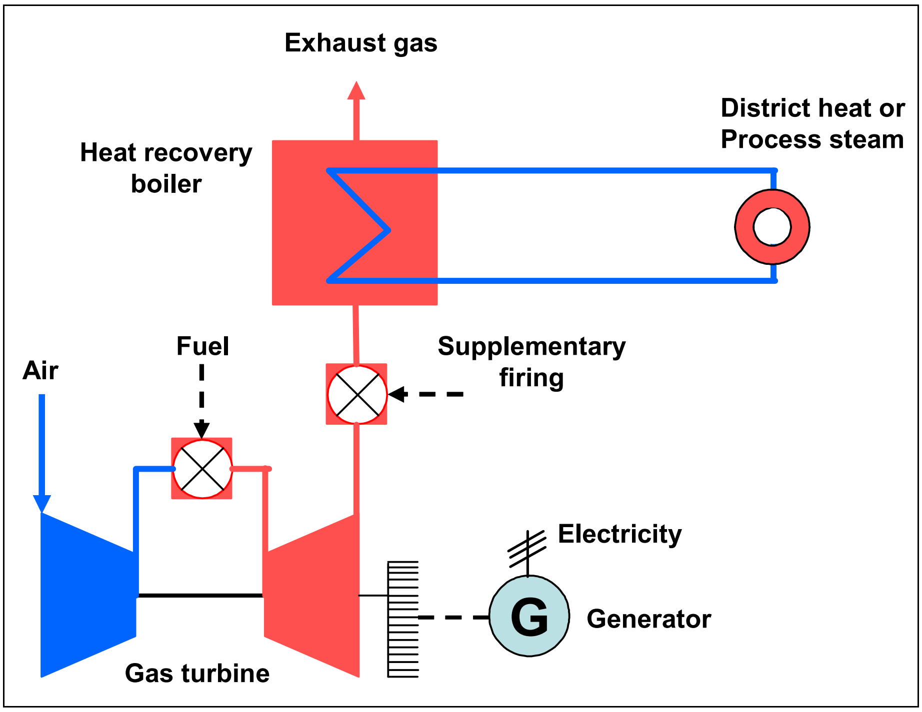


**Figure 3.12: Gas turbine heat recovery boiler**
**[65, Nuutila, 2005]**

*Combined cycle power plant*
A combined cycle power plant consists of one or more gas turbines connected to one or more steam turbines (see Figure 3.13). A combined cycle power plant is often used for combined heat and power production. The heat from the exhaust gases of a gas turbine process is recovered for the steam turbine process. The benefit of the system is a high power to heat ratio and a high efficiency. The latest development in combustion technology, the gasification of solid fuel, has also been linked with combined cycle plants. The gasification technique will reduce the sulphur and nitric oxide emissions to a considerably lower level than conventional combustion techniques by means of the gas treatment operations downstream of gasification and upstream the gas turbine combined cycle.

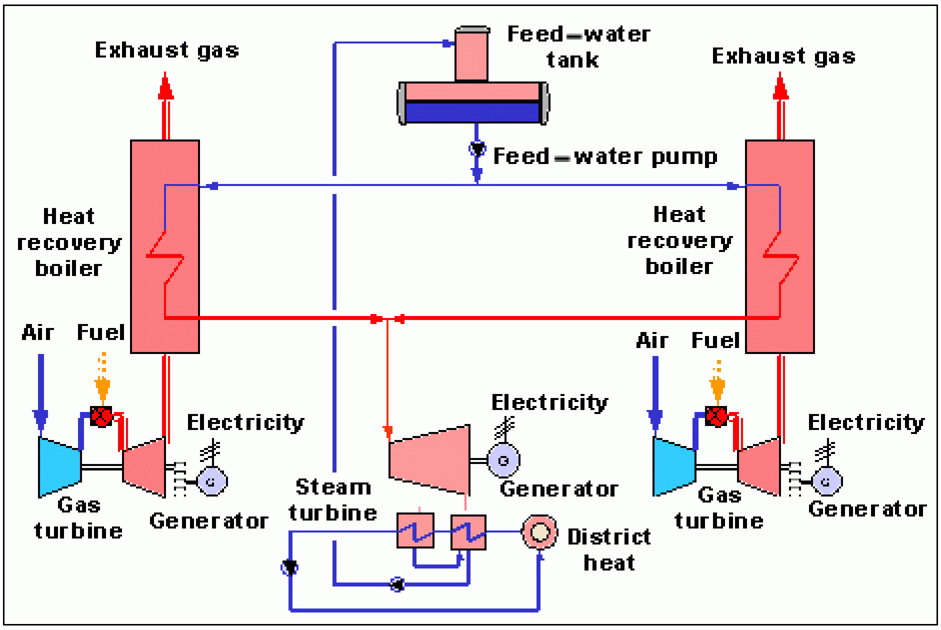


**Figure 3.13: Combined cycle power plant**
**[65, Nuutila, 2005]**

*Internal combustion engines (reciprocating engines)*
In an internal combustion or reciprocating engine, heat can be recovered from lubrication oil and engine cooling water as well as from exhaust gases as shown in Figure 3.14.

Internal combustion engines convert chemically bound energy in fuel to thermal energy by combustion. Thermal expansion of flue-gas takes place in a cylinder, forcing the movement of a piston. The mechanical energy from the piston movement is transferred to the flywheel by the crankshaft and further transformed into electricity by an alternator connected to the flywheel. This direct conversion of the high temperature thermal expansion into mechanical energy and further into electrical energy gives internal combustion engines the highest thermal efficiency (produced electric energy per used fuel unit) among single cycle prime movers, i.e. also the lowest specific $CO_2$ emissions.

Low speed (<300 rpm) two stroke engines are available up to 80 $MW_e$ unit sizes. Medium speed (300 <n <1500 rpm) four stroke engines are available up to 20 $MW_e$ unit sizes. Medium speed engines are usually selected for continuous power generation applications. High speed (>1500 rpm) four stroke engines available up to around 3 $MW_e$ are mostly used in peak load applications.

The most used engine types can further be divided into diesel, spark/micro pilot ignited and dual fuel engines. Covering a wide range of fuel alternatives from natural, associated, landfill, mining (coal bed), bio and even pyrolysis gases and liquid biofuels, diesel oil, crude oil, heavy fuel oil, fuel emulsions to refinery residuals.

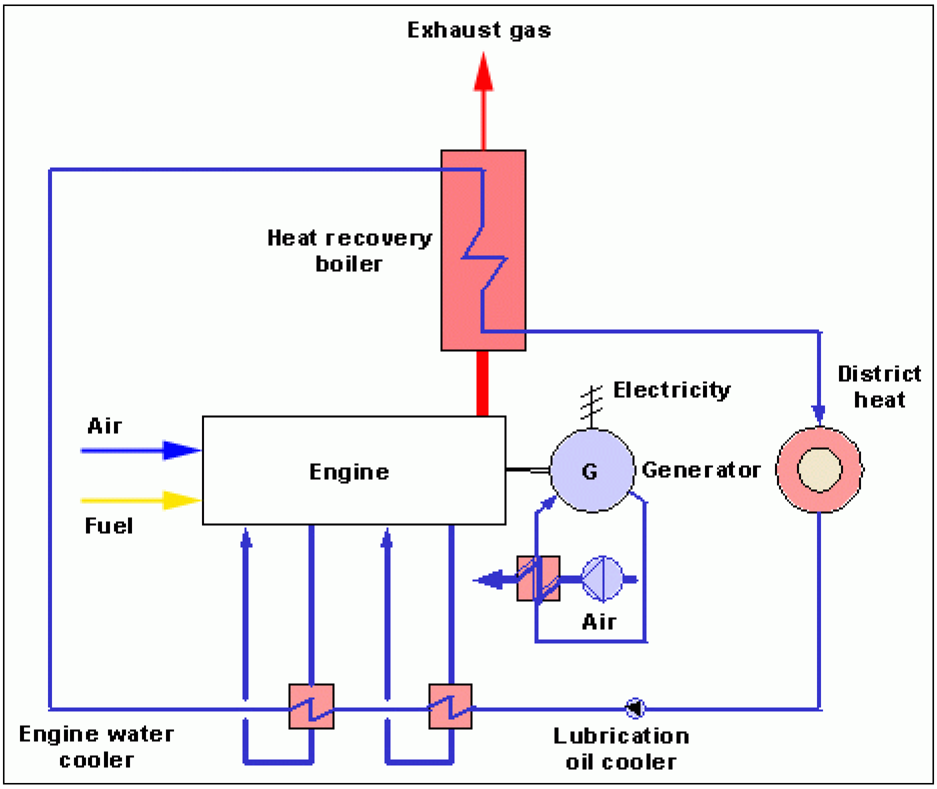


**Figure 3.14: Internal combustion or reciprocating engine**
**[65, Nuutila, 2005]**

Stationary engine plants (i.e. not mobile generators) commonly have several engine driven generator sets working in parallel. Multiple engine installations in combination with the ability of engines to maintain high efficiency when operated at part load, gives operation flexibility with optimal matching of different load demands and excellent availability. Cold start up time is short compared to a coal, oil or gas fired boiler steam turbine plants or a combined cycle gas turbine plant. A running engine has a quick response capability to network and can therefore be utilised to stabilise the grid quickly.

Closed radiator cooling systems are suitable for this technology, keeping the water consumption of stationary engine plants very low.

Their compact design makes engine plants suitable for distributed combined heat and power (CHP) production, close to electricity and heat consumers in urban and industrial areas. Thus associated energy losses in transformers and transmission lines and heat transfer pipes are reduced. Typical transmission losses associated with central electricity production account, on the average, for 5 to 8 % of the generated electricity, correspondingly heat energy losses in municipal district heating networks are may be less than ?? – 10 %. *(TWG: figures please).* It should be born in mind that the highest transmission losses generally occur in low voltage grids and in house serving connections. On the other hand electricity production in bigger plants usually is more effective.

The high single cycle efficiency of internal combustion engines together with relatively high exhaust gas and cooling water temperatures makes them ideal for CHP solutions. Typically about 30 % of the energy released in the combustion of the fuel can be found in the exhaust gas and about 20 % in the cooling water streams. Exhaust gas energy can be recovered by connecting a boiler down stream of the engine, producing steam, hot water or hot oil. Hot exhaust gas can also be used directly or indirectly via heat exchangers, e.g. in drying processes. Cooling water streams can be divided into low and high temperature circuits and the degree of recovery potential is related to the lowest temperature that can be utilised by the heat customer. The whole cooling water energy potential can be recovered in district heating networks with low return temperatures. Engine cooling heat sources in connection with an exhaust gas boiler and an economiser can then result in a fuel (electricity + heat recovery) efficiency, of up to 85 % with liquid and up to 90 % in gas fuel applications.

Heat energy can be delivered to end users as steam (typically up to 20 bar super heated), hot water or hot oil depending on the need of the end user. The heat can also be utilised by an absorption chiller process to produce chilled water.

It is also possible to use absorption heat pumps to transfer energy from the engine low temperature cooling circuit to a higher temperature that can be utilised in district heating networks with high return temperatures. See Section 3.4.3.

Hot and chilled water accumulators can be used to stabilise an imbalance in electricity, heating and cooling demand over shorter periods.

Internal combustion or reciprocating engines typically have fuel efficiencies in the range of 40 - 48 % when producing electricity and fuel efficiencies may come up to 85 – 90 % in combined heat and power cycles. Flexibility in trigeneration can be improved by using hot water and chilled water storage, and by using the topping-up control capacity offered by compressor chillers or direct-fired auxiliary boilers.

**Achieved environmental benefits**

There are significant economic and environmental advantages to be gained from CHP production. Combined cycle plants make the maximum use of the fuel's energy by producing both electricity and heat with minimum energy wastage. The plants achieve a fuel efficiency of 80 to 90 per cent, while for the conventional steam condensing plants the efficiencies remain at 35 % – 45 % and even for the combined cycle plants below 58 %.

The high efficiency of CHP processes delivers substantial energy and emission savings. Figure 3.15 shows typical values of a coal-fired CHP plant compared to the process in an individual heat-only boiler and a coal-fired electricity plant, but similar results can also be obtained with other fuels. The numbers in Figure 3.15 are expressed in dimensionless energy units. In this example, separate and CHP units produce the same amount of useful output. However, separate production implies an overall loss of 98 energy units, compared to only 35 in CHP. The fuel efficiency in the separate production is 55 % while in the case of combined heat and power production 84 % fuel efficiency is achieved. CHP production thus needs around 30 % less fuel input to produce the same amount of useful energy.

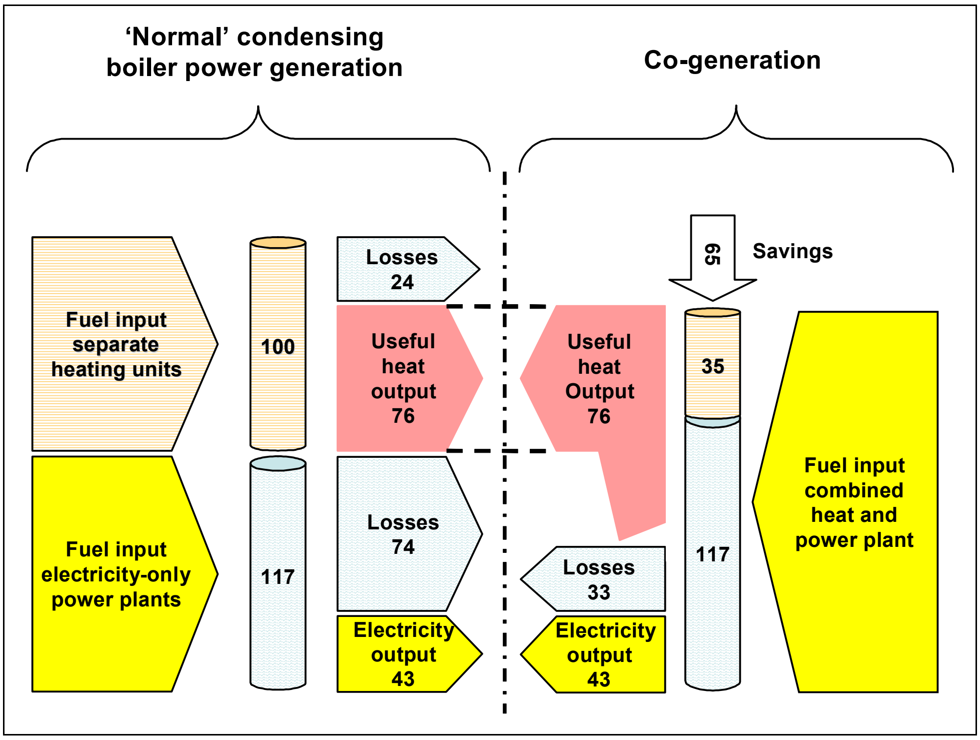


**Figure 3.15: Comparison between efficiency of a condensing power and a combined heat and power plant**
**[65, Nuutila, 2005]**

The fuel neutrality of CHP, which can use a wide range of different fuels from biomass to coal and gas, also contributes to a greater diversity in the fuel mix thereby further decreasing the energy dependency.

### Cross-media effects

The electricity production may decrease where a plant is optimised for heat recovery (e.g in W-t-E plants, see the WI BREF)

### Operational data

See Descriptions of different cogeneration techniques above.

**Applicability**
The choice of CHP concept is based on a number of factors and even with similar energy requirements, no two sites are the same. The initial selection of a CHP plant is often dictated by the following factors:

- the site heat demand, in terms of quantity, temperature etc. that can be met using heat from the CHP plant
- the base-load electrical demand of the site, i.e. the level below which the site electrical demand seldom falls
- the concurrent demands for heat and power
- a convenient fuel price in ratio to the price of electricity
- high annual operation time (preferably more than 4.000 – 5.000 full load hours).

In general CHP units are applicable to plants having significant heat demands at temperatures within the range of medium or low pressure steam. The evaluation of the cogeneration potential at a site should ensure that no significant heat demand reductions can be expected. Otherwise the cogeneration setup would be designed for a too large heat demand, and the cogeneration unit would operate inefficiently.

Today, relatively small scale CHP can be economically feasible (see [Atrium hospital]). The following paragraphs explain which types of CHP are usually suitable in different cases. However, the limiting figures are exemplary only and may depend on local conditions. Usually the electricity can be sold to the national grid as the site demand varies.

Utilities modelling, Section 2.7.5 assists the optimisation of the generation and heat recovery systems, as well as managing the selling and buying of surplus energy.

Choice of CHP type
Steam turbines may be the appropriate choice for sites where:

- the electrical base load over 3 - 5 $MW_e$
- there is a low value process steam requirement; and the power to heat demand ratio is greater than 1:4
- cheap, low premium fuel is available
- adequate plot space is available
- high grade process waste heat is available (e.g. from furnaces or incinerators)
- the existing boiler plant is in need of replacement
- power to heat ratio is to be minimised. In CHP plants the back-pressure level must be minimised and the high pressure level must be maximised in order to maximise the power to heat ratio, especially when renewable fuels are used.

Gas turbines may be suitable if:

- power to heat ratio is planned to be maximised
- the power demand is continuous, and is over 3 $MW_e$ (smaller gas turbines are just starting to penetrate the market)
- natural gas is available (although this is not a limiting factor)
- there is a high demand for medium/high pressure steam or hot water, particularly at temperatures higher than 500°C
- demand exists for hot gases at 450 C or above – the exhaust gas can be diluted with ambient air to cool it, or put through an air heat exchanger. (Also consider using in a combined cycle with a steam turbine).

Internal combustion or reciprocating engines may be suitable for sites where:

- power, or processes are cyclical or not continuous
- low pressure steam or medium or low temperature hot water is required
- there is a high power to heat demand ratio
- natural gas is available – gas powered internal combustion engines are preferred
- natural gas is not available – fuel oil or LPG powered diesel engines may be suitable
- the electrical load is less than 1 $MW_e$ – spark ignition (units available from 0.003 to 10 $MW_e$)
- the electrical load is greater than 1 $MW_e$ – compression ignition (units from 3 to 20 $MW_e$).

**Economics**

- the economics depends on the ratio between fuel and electricity price
- policy support and market mechanisms have a significant impact, such as the beneficial energy taxation regime, and liberalisation of the energy markets.

**Driving force for implementation**

Policy mechanisms (see Economics, above).

**Examples**:

- Äänekoski CHP power plant, Finland
- Rauhalahti CHP power plant, Finland
- used in soda ash plants, see the LVIC-S BREF
- Bindewald Kupfermühle, DE:
    - flour mill: 100000 t wheat and rye/yr
    - malthouse: 35000 t malt /yr

**Reference information**

[65, Nuutila, 2005], [97, Kreith, 1997] [127, TWG, , 128, EIPPCB, , 140, EC, 2005, 146, EC, 2004]

### 3.4.2 Trigeneration

**Description**

Trigeneration is generally understood to mean the simultaneous conversion of a fuel into three useful energy products: electricity, hot water or steam and chilled water. A trigeneration system is actually a cogeneration system (Section 3.4) with an absorption chiller that uses some of the heat to produce chilled water (See Figure 3.16).

Figure 3.16 compares two concepts of chilled water production: compressor chillers using electricity and trigeneration using recovered heat in a lithium bromide absorption chiller. As shown, heat is recovered from both the exhaust gas and the engine high temperature cooling circuit. Flexibility in trigeneration can be improved by using topping-up control capacity offered by compressor chillers or direct-fired auxiliary boilers.

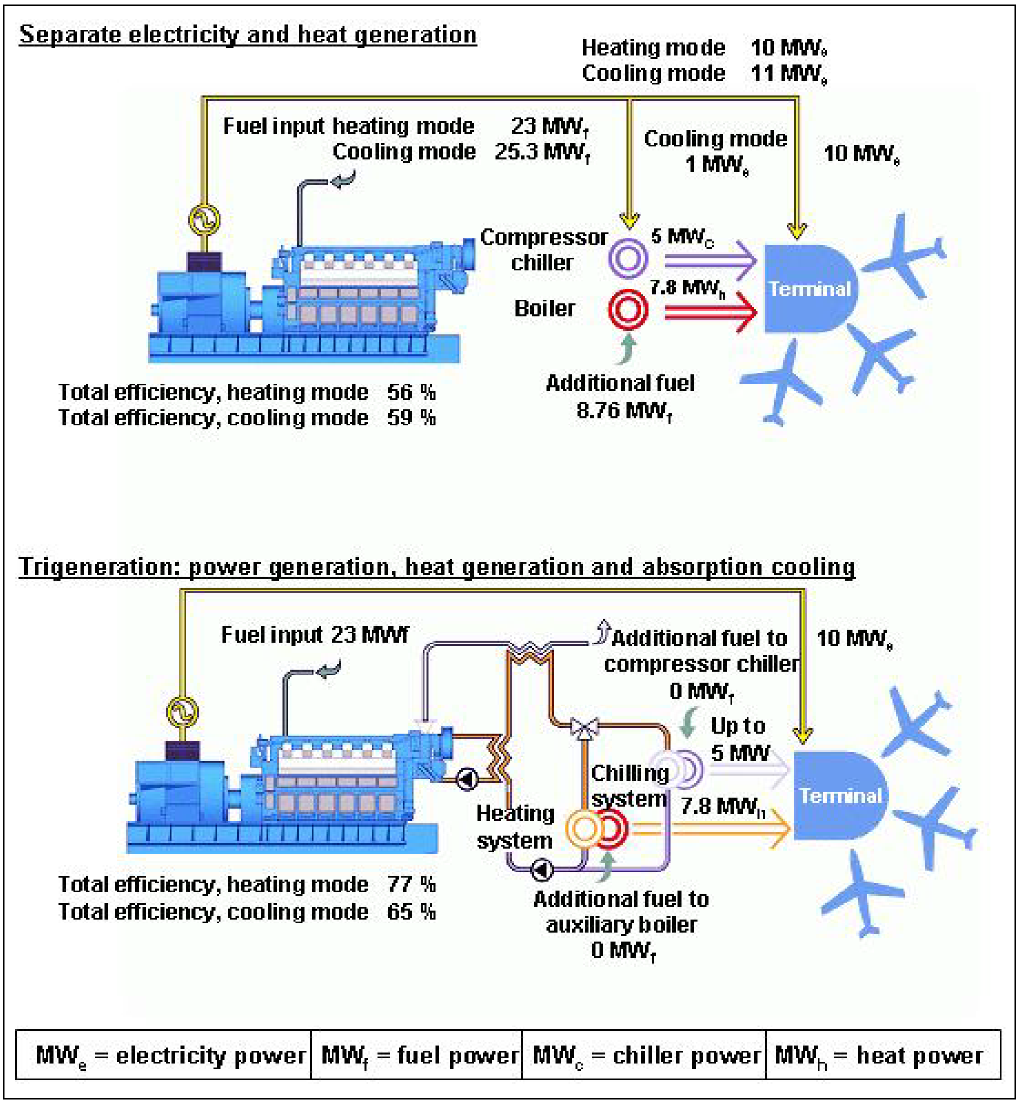


**Figure 3.16: Trigeneration compared to separate energy production**
**[64, Linde, 2005]**

Single-stage lithium bromide absorption chillers are able to use hot water with temperatures as low as 90 C as the energy source, while two-stage lithium bromide absorption chillers need about 170 C, which means that they are normally steam-fired. A single-stage lithium bromide absorption chiller producing water at 6 – 8 C has a coefficient of performance (COP) of about 0.7 and a two-stage chiller has a COP of about 1.2. This means they can produce a chilling capacity corresponding to 0.7 or 1.2 times the heat source capacity.

For an engine-driven CHP plant, single- and two-stage systems can be applied. However, as the engine has residual heat split in exhaust gas and engine cooling, the single stage is more suitable because more heat can be recovered and transferred to the absorption chiller.

**Achieved environmental benefits**

The main advantage of trigeneration is the achievement of the same output with considerably less fuel input than with separate power and heat generation.

The flexibility of using the recovered heat for heating during one season (winter) and cooling during another season (summer) provides an efficient way of maximising the running hours at high total plant efficiency, benefiting both the owner and the environment – see Figure 3.17.

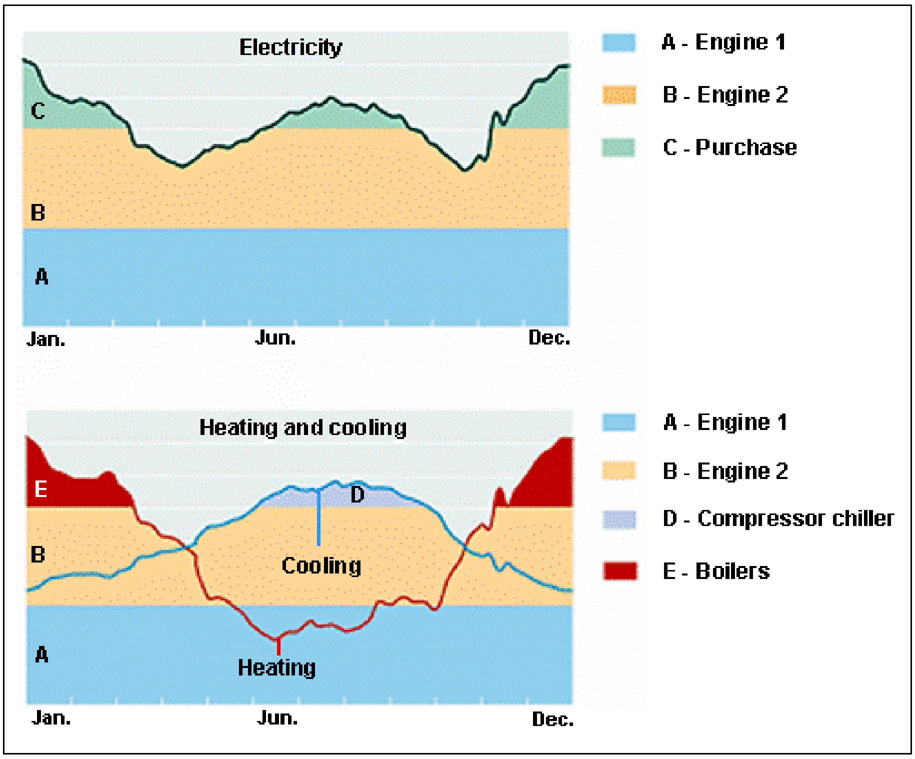


**Figure 3.17: Trigeneration enables optimised plant operation throughout the year**
**[64, Linde, 2005]**

The running philosophy and control strategy are of importance and should be properly evaluated. The optimal solution is seldom based on a solution where the entire chilled water capacity is produced by absorption chillers. For air conditioning, for instance, most of the annual cooling needs can be met with 70 % of the peak cooling capacity, while the remaining 30 % can be topped up with compressor chillers.

In this way, the total investment cost for the chillers can be minimised.

**Cross-media effects**

None.

**Operational data**

**Applicability**

*Trigeneration and distributed power generation*

Since it is more difficult and costly to distribute hot or chilled water than electricity, trigeneration automatically leads to distributed power production since the trigeneration plant needs to be located close to the hot or chilled water consumers.

In order to maximise the fuel efficiency of the plant, the concept is based on the joint need for hot and chilled water. A power plant located close to the hot and chilled water consumer also has lower electricity distribution losses. Trigeneration is cogeneration taken one step further by including a chiller. Clearly there is no advantage to making that extra investment if all the recovered heat can be used effectively during all the plant's running hours.

However, the extra investment starts to pay off if there are periods when not all the heat can be used, or when no heat demand exists but there is a use for chilled water or air. For example, trigeneration is often used for air conditioning in buildings, for heating during winter and cooling during summer, or for heating in one area and cooling in another area.

Many industrial facilities and public buildings also have such a suitable mix of heating and cooling needs, four examples being breweries, shopping malls, airports and hospitals.

**Economics**

**Driving force for implementation**

Cost savings.

**Examples**

Madrid Barajas Airport, ES (see Annex 10)
Atrium Hospital, NL

**Reference information**

[64, Linde, 2005, 93, Tolonen, 2005]

### 3.4.3 District cooling

**Description**

Cogeneration can also deliver district cooling (DC) by means of centralised production and distribution of cooling energy. Cooling energy is delivered to customers via chilled water transferred in a separate distribution network.

District cooling can be produced in different ways depending on the season and the outside temperature. In the winter, at least in Nordic countries, cooling can be carried out by cold water from the sea (see Figure 3.18). In the summer, district cooling can be produced by absorption technology (see Figure 3.18), see Section 3.3.2. District cooling is used for air conditioning, for cooling of office and commercial buildings, and for residential buildings.

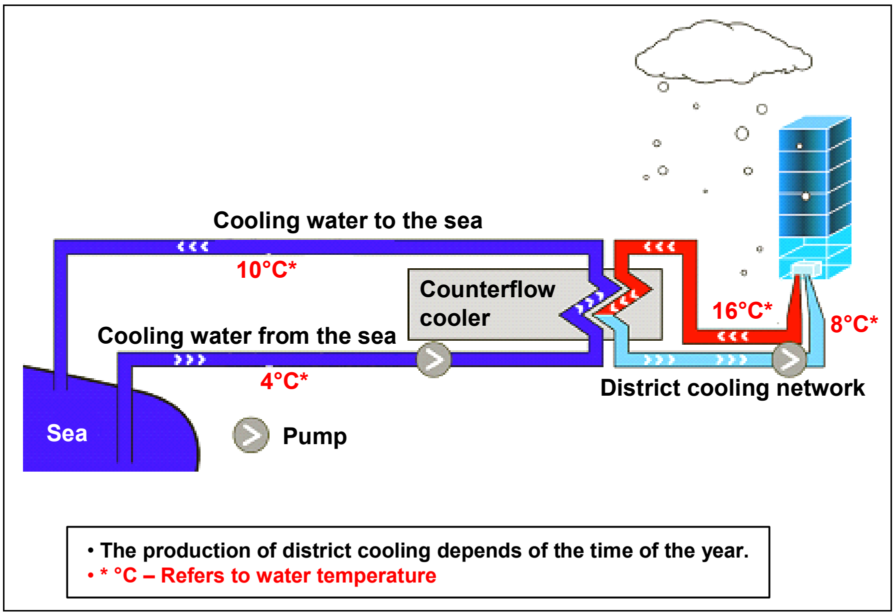


**Figure 3.18: District cooling in the winter by free cooling technology**
**[93, Tolonen, 2005]**

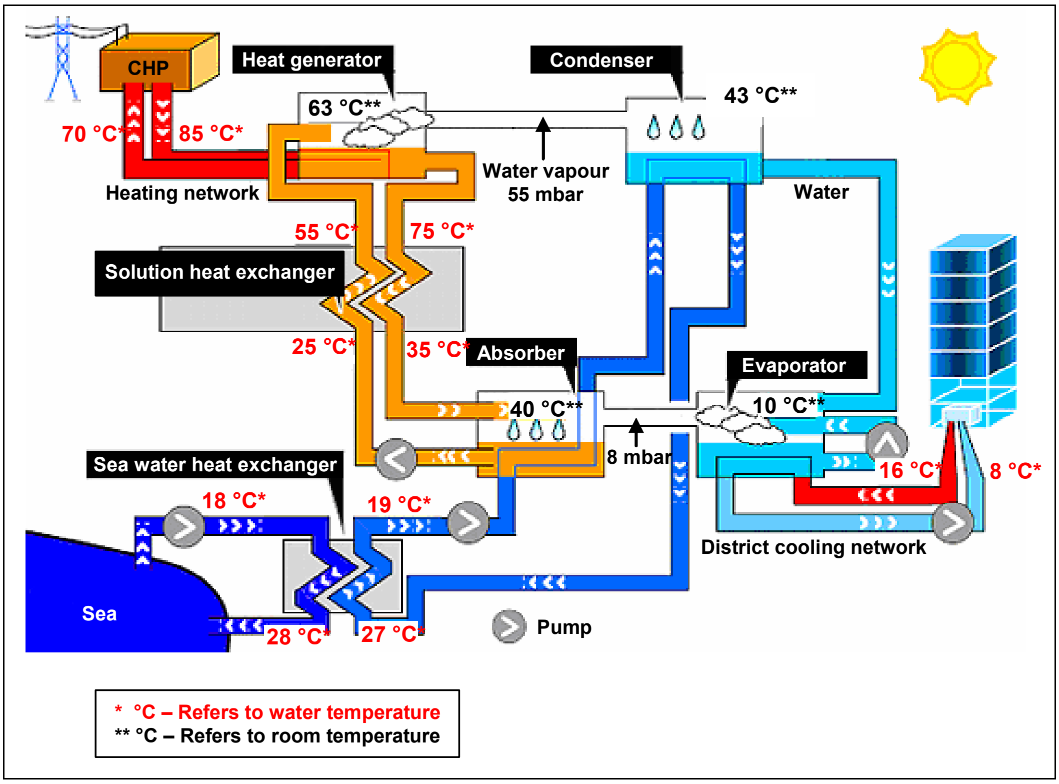


**Figure 3.19: District cooling by absorption technology in the summer**
**[93, Tolonen, 2005]**

*TWG: The inlet and outlet temperatures shown in the seawater heat exchanger appear incorrect. It is not possible that the seawater outlet temperature is higher then the inlet temperature of the circulating water. Please clarify.*

**Achieved environmental benefits**
Improving the eco-efficiency of district heating (DH) and district cooling (DC) in Helsinki, Finland, has already achieved many sustainability goals as shown below:

- greenhouse gas and other emissions, such as nitrogen oxides, sulphur dioxide and particles, have been greatly reduced
- the drop in electricity consumption will also cut down the electricity consumption peaks that building-specific cooling units cause on warm days
- from October until May, all DC energy is renewable, obtained from cold seawater. This represents 30 % of yearly DC consumption
- in the warmer season, absorption chillers use the excess heat of CHP plants which otherwise would be led to the sea. Although the fuel consumption in the CHP plant may increase, the total fuel consumption compared to the situation with separate cooling systems in buildings will decrease
- in DC, harmful noise and vibration of cooling equipment has been removed
- the space reserved for cooling equipment in buildings is freed for other purposes
- the problem of microbial growth in the water of condensing towers is also avoided
- contrary to the cooling agents used in building-specific compressor cooling, no harmful substances (e.g. CFC and HCFC compounds) evaporate in the processes of DC
- DC improves the aesthetics of cityscape: the production units and pipelines are not visible. The big condensers on the roofs of buildings and multiple coolers in windows will no longer be needed
- the life cycle of the DH and DC systems is much longer than that of building-specific units, e.g. the service life of a cooling plant is double compared to separate units. The technical service life of a DH and DC main pipelines extends over a century.

**Cross-media effects**

Impacts of installing distribution system.

**Operational data**

Reliable.

**Applicability**

This technique could have wide application. However, this depends on local circumstances.

**Economics**

Large investments are required for the distribution systems.

**Driving force for implementation**

**Example**

Helsinki Energy, Finland.

**Reference information**

[93, Tolonen, 2005], [120, Helsinki Energy, 2004]

## 3.5 Electrical power supply

**Introduction**

Public electrical power is supplied via high voltage grids where the voltage and current vary in sine wave cycles at 50 Hz (in Europe) in three phases at 120 ° intervals. The voltage is high to minimise current losses in transmission. Depending on the equipment to be used, the voltage is stepped down on entering the site, or close to specific equipment, usually to 440V for industrial use, and 240V for offices, etc.

Various factors affect the delivery and use of energy, including the resistance in the delivery systems, and the effects some equipment and uses have on the supply. Stable voltages and undistorted waveforms are highly desirable in power systems.

The consumption of electrical energy in the EU-25 in 2002, comprises 2641 TWh plus 195 TWh network losses. The largest consumer sector is industry with 1168 TWh (44 %), followed by households, with 717 TWh (27 %), and services with 620 TWh (23 %). These three sectors together account for around 94 % of consumption.

### 3.5.1 Power factor correction

**Description**

Many electrical devices have inductive loads, such as:

- AC single-phase and 3-phase motors
- variable speed drives
- transformers
- high-intensity discharge lighting.

These require both active power and reactive power. The active power is converted into useful mechanical power, while the reactive power is used to maintain the device's magnetic fields. This reactive power is transferred periodically in both directions between the generator and the load (at the same frequency as the supply). Capacitor banks and buried cables also take reactive energy.

Vector addition of the real (active) power and the reactive power gives the apparent power. Power generation utilities and network operators must make this apparent power available and transmit it. This means that generators, transformers, power lines, switchgear, etc. must be sized for greater power ratings than if the load only drew active power.

Power supply utilities (both on-site and off-site) are faced with extra expenditure on equipment and additional power losses. External suppliers therefore make additional charges for reactive power if this exceeds a certain threshold. Usually, a certain target power factor of cos φ of between 1.0 and 0.9 (lagging) is specified, at which point the reactive energy requirement is significantly reduced. A simple explanation is given in Annex 15.

$$\text{Power factor} = \frac{\text{Real power}}{\text{Apparent power}}$$

For example, using the power triangle illustrated below, if:

real power = 100 kW and apparent power = 142 kVA t

then the power factor = 100/142 = 0.70 or 70 %.

This indicates that only 70 % of the current provided by the electrical utility is being used to produce useful work.

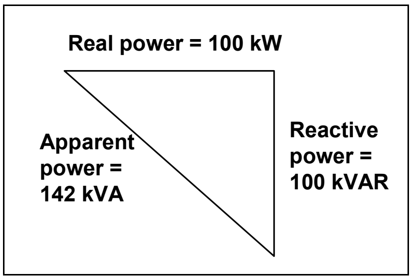


**Figure 3.20: Reactive and apparent power**

If the power factor is corrected, for example by installing a capacitor at the load, this totally or partially eliminates the reactive power draw at the power supply company. Power factor correction is at its most effective when it is physically near to the load and uses state-of-the-art technology.

The power factor can change over time so needs to be checked periodically (depending on site and usage, about 3 to 10 years), as the type of equipment and the supplies listed (above) change over time. Also, as capacitors used to correct the power factor deteriorate with time, and these require periodic testing (most easily by checking if the capacitors are getting warm in operation).

Other measures to take are:

- minimise operation of idling or lightly loaded motors (see Section 3.6)
- avoid operation of equipment above its rated voltage
- replace standard motors as they burn out with energy-efficient motors(see Section 3.6)
- even with energy-efficient motors, however, the power factor is significantly affected by variations in load. A motor must be operated near its rated capacity to realize the benefits of a high power factor design (see Section 3.6).

### Achieved environmental benefits

These are the energy savings to both the supply side and the consumer.

Table 3.20 below shows the effects of a power factor of 0.95 (lagging) being achieved in EU industry as a whole.

| EU-25 industry power factor | Active energy TWh | Cos φ | Reactive energy TVArh | Apparent energy TVAh |
|---|---|---|---|---|
| Estimated power factor | 1 168 | 0.70 | 1192 | 1669 |
| Targeted power factor | 1 168 | 0.95 | 384 | 1229 |

**Table 3.20: Estimated industry electricity consumption in the EU-25 in 2002**
**actual figure, [131, ZVEI, , 140, EC, 2005], calculations [131, ZVEI, , 140, EC, 2005]**

Across the EU as a whole, it has been estimated that if a power correction factor for industry was applied, then 31 TWh of power could be saved, although part of this potential has been exploited. (This is calculated on the basis that the EU-25 total electricity consumption for industry and service sectors in 2002 was 1788 TWh, of which industry was 65 %)[12].

In the installation, it is estimated that if an operator with a power correction factor of 0.73 corrected the factor to 0.95, they would save 0.6 % of their power usage (0.73 is the estimated figure for industry and services).

### Cross-media effects

None reported

### Operational data

Uncorrected power supply will cause power losses in the installation's distribution system. Voltage drops may occur as power losses increase. Excessive drops can cause overheating and premature failure of motors and other inductive equipment.

### Applicability

All sites.

### Economics

External suppliers may make additional charges for excessive reactive power if the correction factor in the installation is less than 0.95 (see Section 5.2).

The cost of power correction is low. Some new equipment (e.g. high efficiency motors) addresses power correction.

### Driving force for implementation

Power savings both inside the installation and in the external supply grid (where used).
Increase in internal electrical supply system capacity.
Improved equipment reliability and reduced downtimes.

### Examples

Widely applied.

### Reference information

[130, US_DOE_PowerFactor, , 131, ZVEI]

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[12] 31 TWh corresponds to over 8 million households, about 2600 wind power generators, about 10 gas-fired power stations, and 2 – 3 nuclear power stations. It also corresponds to more than 12 Mt of $CO_2$.

### 3.5.2 Harmonics

**Description**
Certain electrical equipment with non-linear loads causes harmonics in the supply (the addition of the distortions in the sine wave). Examples of non-linear loads are rectifiers, some forms of electric lighting, electric arc furnaces, welding equipment, switched mode power supplies, computers, etc.

Filters can be applied to reduce or eliminate harmonics. The EU has set limits on harmonics as a method of improving power factor, and there is a standard EN 61000-3-2 requiring switched power supplies to have harmonics filters *(TWG: does this refer only to small devices, e.g. domestic?).*

**Achieved environmental benefits**
Power saving.

**Cross-media effects**
None reported.

**Operational data**
Harmonics can cause:

- nuisance tripping of circuit breakers
- malfunctioning of UPS systems and generator systems
- metering problems
- computer malfunctions
- overvoltage problems.

Harmonics cannot be detected by standard ammeters, but by using 'true RMS' meters.

**Applicability**
All sites should check for equipment causing harmonics.

**Economics**
Losses due in equipment malfunction.

**Driving force for implementation**
Improved reliability of equipment.
Reduced losses in downtimes.
With harmonics, reduced current in earths.
The safety issues of design grounding being exceeded if harmonics are present.

**Examples**
Widely used.

**Reference information**
[132, Wikipedia_Harmonics, , 135, EUROELECTRICS, , 136, CDA]

### 3.5.3 Optimising supply

**Description**

Resistive losses occur in cabling. Equipment with a large power usage should therefore be supplied from a high voltage supply as close as possible, i.e. the corresponding transformer should be as close as possible, etc.

Cables to equipment should be oversized to prevent unnecessary resistance and losses as heat.

The power supply can be optimised by using high efficiency equipment such as transformers.

Other high efficiency equipment such as motors, is covered in Section 3.6, compressors 3.7, pumps Section 3.8.

**Achieved environmental benefits**

**Cross-media effects**

**Operational data**

All large power using equipment should be planned to be adjacent to supply transformers.
Cabling should be checked on all sites and oversized where necessary.

**Applicability**

Improved reliability of equipment.
Reduced losses in downtimes.
Consider the costs on an operating lifetime basis.

**Economics**

Savings in equipment downtime and power consumption.

**Driving force for implementation**

Cost.

**Examples**

Widely used.

**Reference information**

[Correspondence, Eurelectric]
http://www.copper.org/applications/electrical/pq/issues.html

## 3.6 Electric motor driven sub-systems[13]

**Description**

An electric motor driven sub-system converts electric power into mechanical power. In most industrial applications, the mechanical work is transferred to the driven machine as rotational mechanical power (via a rotating shaft). Electric motors are the prime movers behind most industrial machinery: pumps, fans, compressors, mixers, conveyors, debarking drums, grinders, saws, extruders, centrifuges, presses, rolling mills, etc.

Electrical motors are one of the main energy consumption sources in Europe. Estimates are that motors account for:

- 70 % of the electricity consumed in industry which amounted to 89 TWh in 1997. *TWG: Different sources give values of 65 % or 70 %. Advise?*
- 1/3 of the tertiary electrical consumption.

An *electric motor driven sub-system* is a sub-system or a train of components consisting of:

- an installation power supply
- a control device, e.g. AC drive (see below)
- an electric motor, usually an induction motor
- a mechanical transmission coupling
- a driven machine, e.g. centrifugal pump.

*Driven machine*: also referred to as a load machine, this is the machine that carries out a value-added task related to the ultimate purpose of the industrial plant. The tasks performed can be divided into two main categories as the driven machine can either:

- alter properties in some ways: altering pressure (compressing, pumping), altering physical shape (crushing, wire drawing, rolling metals, etc.). It is the pressure-changing function that is used in larger systems that are described in more detail in this document (% motor energy used in the EU-15 by machine type):
  - pumps (20 % ), see Section 3.8
  - fans (18 %), see Section 3.10
  - air compressors (17 %), see Section 3.7
  - cooling compressors (11 %), see Sections 3.4.2 and 3.8

- move or transport material/objects (conveyors, cranes, hoists, winches, etc.):
  - conveyors (4 %) and other uses (30 %: *TWG: does this include the shape changing functions?*).

The electricity consumption of motor systems is influenced by many factors such as:

- motor efficiency
- proper sizing
- motor controls: stop/start and speed control
- power supply quality
- mechanical transmission system
- maintenance practices
- the efficiency of end-use device.

In order to benefit from the available savings potential, the users should aim to optimise the whole system that the motor sub-system is part of, before considering the motor subsection (see Sections 1.4.2, 1.5.2, and the individual systems section in this chapter).

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[13] In this document 'system' is used to refer to a set of connected items or devices which operate together for a specific purpose, e.g. HVAC, CAS. See the discussion on system boundaries. These systems usually include motor sub-systems (or component systems).

*Mechanical transmission*
Mechanical transmission connects the driven machine and the motor together mechanically. This may be a simple, rigid coupling that connects the shaft ends of the machine and the motor, a gearbox, a chain or belt drive, or a hydraulic coupling. All these types incur additional power losses in the drive system.

*Electric motor*
Electric motors can be divided into two main groups, DC motors (direct current) and AC motors (alternating current). Both types exist in industry, but the technology trend during the last few decades has strongly been towards AC motors.

The strengths of AC motors are:

- robustness, simple design, low maintenance requirement
- a high efficiency level (especially high power motors)
- relatively cheap in price.

AC induction motors are widely used because of these strengths. However, they operate only at one rotating speed. If the load is not stable, there is a need to change the speed and it can be done most energy efficiently by installing a drive before the motor.

Singly-fed electric motors are the most common type of industrial electric motors. They incorporate a single multiphase winding set that actively participates in the energy conversion process (i.e. singly-fed). Singly-fed electric machines operate under either:

- induction (asynchronous) motors which exhibit a startup torque (although inefficiently) and can operate as standalone machines. The induction motor technology is well suited to motors up to several megawatts in power
- synchronous motors which are fundamentally single speed machines. These do not produce useful start-up torques and must have an auxiliary means for start-up and practical operation, such as an electronic controller. Synchronous motors are often built for high power applications, such as compressors in the petrochemical industry.

A DC technology is the ‘permanent magnet’ (PM), or brushless, synchronous motors, which are suitable for applications that require lower rotating speeds than what is typically achieved using induction motors. In these slower-speed applications (220 – 600 RPM), such as so-called sectional drives of paper or board machines, a mechanical transmission (gearbox) can often be eliminated using PM motors, which improves the total efficiency of the system.

**Figure 3.21: A compressor motor with a rated output of 24 MW**
**[95, Savolainen, 2005]**

The strengths with DC motors have traditionally been ease of electrical control of speed and torque. Also the starting torque is high, which is beneficial in some applications. However, the fast development of power electronic components and control algorithms has improved the position of AC technology so that there is no real performance superiority of DC technology over AC any more. Modern AC motors and drives outperform their DC counterparts in many respects. In other words; even the most demanding applications, such as controlling the speed and torque of paper machine winders can be realised with AC motors and drives nowadays.

*Control device*
In its simplest form, this is a switch or a contactor to connect and disconnect the motor from the mains. This can be operated manually or remotely using a control voltage. Motor protection functions may have been incorporated into these devices, and a motor starter is a switch with safety functions built-in.

A more advanced method to connect a motor to the mains is a 'soft starter' (aka: star-delta starter). This device enables moderated start-up of an AC motor, reducing the so-called 'inrush current' during starting, thus protecting mechanics and fuses. Without a soft-start feature, an AC motor starts up and accelerates vigorously to its rated speed. However, a soft starter is NOT an energy saving device, even though there are some misconceptions and sources claiming this.

The only way the devices above can contribute to energy efficiency is that motors can be switched off when not needed.

'Real' motor control devices are able to regulate the output (speed and torque) of electric motors. The operation principle of an AC drive is to convert the frequency of the grid electricity (50 Hz in Europe) to another frequency for the motor in order to be able to change its rotating speed. The control device for AC motors is called the following:

- a 'frequency converter'
- a 'variable speed drive' (VSD)
- an 'adjustable frequency drive' (AFD)
- a combination of them (ASD, VFD) are frequently used to describe the same devices
- 'motor inverter' or just 'inverter' is used by the actual users within industry.

**Achieved environmental benefits**

Motor-driven systems consume about 65 % of industrial energy in the European Union. The energy saving potential in EU-15 industries using AC drives is 43 TWh/yr and for improving the efficiency of electric motors themselves 15 TWh/yr according to EU-15 SAVE studies.

There are at least two different ways to approach the concept of energy efficiency in motor driven systems. One is to look at individual components and their efficiencies, and ensure that only high efficiency equipment is employed.

Table shows potentially significant energy saving measures which might be applicable to a motor sub-system. Although the values in the table are typical, the applicability of the measures will depend on the specific characteristics of the installation.

| **Driven system energy savings measure** | **Typical savings range** |
|---|---|
| **System installation or renewal** | |
| Energy efficient motors (EEM) | 2 – 8 % |
| Correct sizing | 1 – 3 % |
| Energy efficient motor repair (EEMR) | 0.5 – 2 % |
| Variable speed drives (VSD) | 10 – 50 % |
| High efficiency transmission/reducers | 2 – 10 % |
| Power quality control | 0.5 – 3 % |
| **System operation and maintenance** | |
| Lubrication, adjustments, tuning | 1 – 5 % |

**Table 3.21: Drive sub-system power energy saving measures**

Another way to approach the concept of energy efficiency in motor driven systems is to study the demands of the (production) process and how the driven machine should be operated. This is as a system approach, and yields the highest energy efficiency gains (see Section 1.5.2) and is discussed in the relevant sections in this chapter. Savings achieved by a systems approach as a minimum will be those achieved by considering individual components, and can be 30 % or higher (see Section 1.5.1, and, e.g. CAS Section 3.7).

**Cross-media effects**

Harmonics caused by some speed controllers, etc. can cause losses in motors and transformers.

**Operational Data**

*Energy efficient motors (EEMs)*

For an additional cost of 20 – 30 % Energy Efficient Motors (EEMs), also called high efficiency motors (HEMs), will offer 2 – 6 % better efficiency, representing significant energy savings.

As the reduced losses result in a lower temperature rise in the motor, the lifetime of the motor winding insulation, and of the bearings increases. Therefore, in many cases:

- reliability increases
- downtime and maintenance costs are reduced
- tolerance to thermal stresses increases
- ability to handle overload conditions improves
- resistance to abnormal operating conditions – under and over voltage, phase unbalance, poorer voltage and current wave shapes (e.g. harmonics), etc. – improves
- power factor improves
- noise is reduced.

A European-wide agreement between the European Committee of Manufacturers of Electrical Machines and Power Electronics (CEMEP) and the European Commission ensures that the efficiency levels of most electric motors manufactured in Europe are clearly displayed. The European motor classification scheme is applicable to motors <100 kW and basically establishes three efficiency classes, giving motor manufacturers an incentive to introduce higher efficiency models:

- EFF1 (high efficiency motors)
- EFF2 (standard efficiency motors)
- EFF3 (poor efficiency motors)

These efficiency levels apply to 2 and 4 pole three phase AC squirrel cage induction motors, rated for 400 V, 50 Hz, with S1 duty class, with output 1.1 to 90 kW, which account for the largest sales volume in the market.

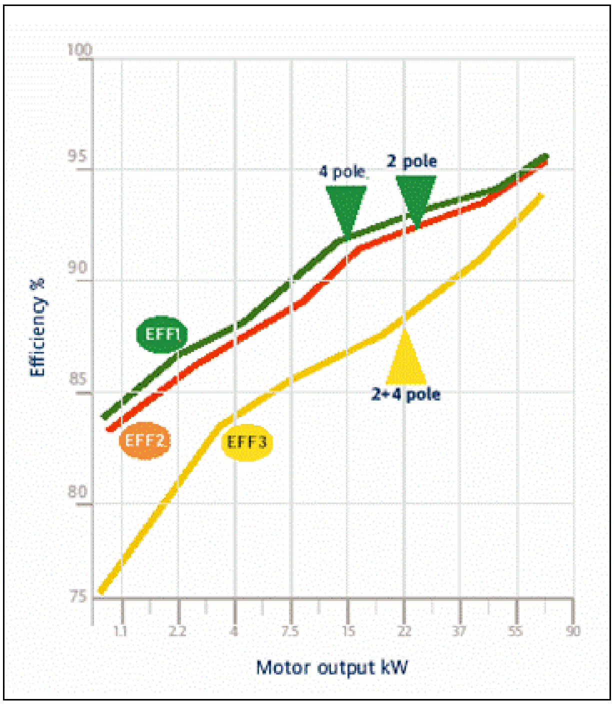

**Figure 3.22: Energy efficiency of three phase AC induction motors**

Appropriate motor solutions may be selected by using of the EURODEEM database[14], which collates the efficiency of more than 3500 types of motors from 24 manufacturers.

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[14] Published by the European Commission

Appropriate motor choice can be greatly aided through the use of adequate computer software, such as Motor Master Plus[15], and EURODEEM[16] proposed at the EU-SAVE PROMOT project.

*Proper motor sizing*

Electrical motors are very often oversized for the real load they have to run. Motors rarely operate at their full-load point. In the European Union, field tests indicate that, on average, the motors operate at around 60 % of their rated load.

The maximum efficiency is obtained for the motors of between 60 to 100 % full load. The induction motor efficiency typically peaks near 75 % of full load and is relatively flat down to the 50 % load point. Under 40 % full load, an electrical motor is not working in optimised conditions and the efficiency falls very quickly. Motors in the larger size ranges can operate with reasonably high efficiency at loads down to 30 % of rated load.

Proper sizing:

- improves energy efficiency, by allowing motors to operate at peak efficiency
- may reduce line losses due to low power factors
- may slightly reduce the operating speed, and thus power consumption, of fans and pumps.

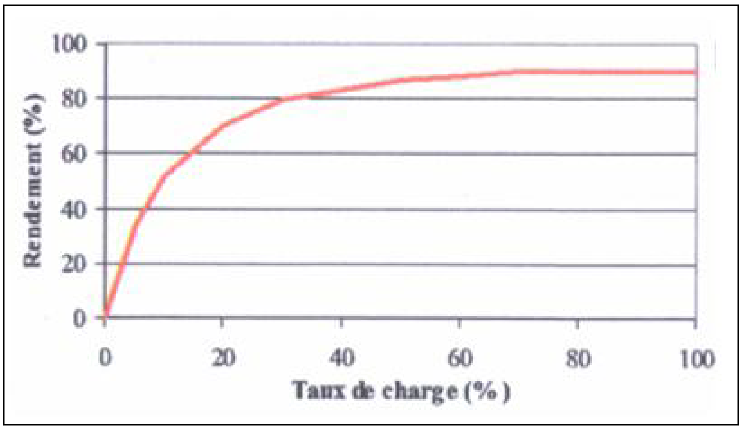

**Figure 3.23: Efficiency vs. load for an electric motor**

*TWG: to be translated if found useful.*

*Motor repair*

When motors above 5 kW fail, they are often repaired several times during their lifetime. Laboratory testing studies confirm that poor motor repair practices reduce motor efficiency typically between 0.5 and 1 %, and sometimes up to 4 % or even more for old motors.

To choose between repair and replacement, electricity cost/kWh, motor power, average load factors and the number of operating hours per year will have to be taken into account.

Typically, replacement of a failed motor through the purchase of a new EEM can be a good option in motors with a large number of operating hours. For example, in a facility with 4000 hours per year of operation, an electricity cost of EUR 0.06/kWh, for motors of between 20 and 130 kW, replacement with an EEM will have a payback time of less than 3 years.

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[15] Sponsored by US Department of Energy

[16] Promoted by the European Commission – DG TREN

*Transmission losses*

Transmission equipment including shafts, belts, chains, and gears should be properly installed and maintained. The transmission system from the motor to the load is a source of losses. These losses can vary significantly, from 0 to 45 %. When possible, use synchronous belts in place of V-belts. Cogged V-belts are more efficient than conventional V-belts. Helical gears are much more efficient than worm gears. Direct coupling has to be the best possible option (where technically feasible), and V-belts avoided.

*Rewinding*

Rewinding a motor is widely carried out in industry. It is cheaper and may be quicker than buying a new motor. However, rewinding a motor can permanently reduce its efficiency by more than 1 %. Proper attention must be given to the repair process and to the repair company, which should be recognised by the original manufacturer. The over cost of a new motor can be quickly compensated by its better energy efficiency, so rewinding may not be economic when considering the life-time cost.

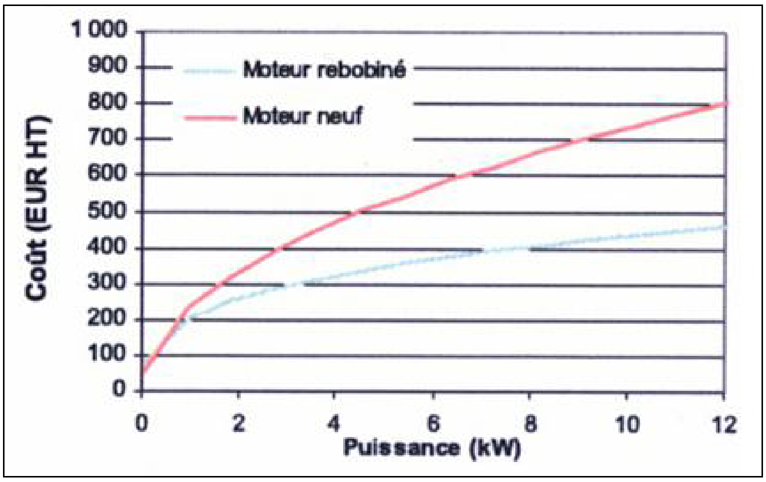

**Figure 3.24: Cost of a new motor compared with rewinding**

*TWG: to be translated if found useful.*

Calculating the payback on buying a higher efficiency motor compared to rewinding a failed standard motor:

$$\text{Payback (in year)} = \frac{Cost_{HEM} - Cost_{old}}{kW \times H \times Cost_{electricity} \times \left[ 1/\eta_{\text{Rewinded}} - 1/\eta_{HEM} \right]}$$

where:

- $Cost_{HEM}$: Cost of the new high efficiency motor
- $Cost_{old}$: Cost of rewinding the old motor
- $Cost_{electricity}$: Cost of electricity
- kW: average power drawn by motor when running.

*Variable speed drives*

The adjustment of the motor speed through the use of variable speed drives (VSDs) can lead to significant energy savings associated to better process control, less wear in the mechanical equipment and less acoustical noise. When loads vary, VSDs can reduce electrical energy consumption particularly in centrifugal pumps, compressor and fan applications – typically in the range of 20 – 50 %. Materials processing applications like centrifugal machines, mills and machine tools, as well as materials handling applications such as winders, conveyors and elevators, can also benefit both in terms of energy consumption and overall performance through the use of VSDs.

The use of VSDs can also lead to other benefits including:

- extending the useful operating range of the driven equipment
- isolating motors from the line, which can reduce motor stress and inefficiency
- accurately synchronising multiple motors
- improving the speed and reliability of response to changing operating conditions.

VSDs are not applicable for all applications, in particular where the load is constant (e.g. fluid bed air input fan, oxidation air compressors etc.), as the VSD will lose 3 – 4 % of the energy input (rectifying and adjusting the current phase).

**Applicability**
Electric motor drives exist in practically all industrial plants, where electricity is available.

The applicability of particular measures, and the extent to which they might save money, depend upon the size and specific nature of the installation. As assessment of the needs of the entire installation and of the system within it can determine which measures are both applicable and profitable. This should be done by a qualified drive system service provider or by qualified in-house engineering staff.

The assessment conclusions will identify the measures which are applicable to a system, and will include an estimate of the savings, the cost of the measure, as well as the payback time.

**Economics**
Over its lifetime, costs associated with operating a motor are shown in Figure 3.24 (approximately):

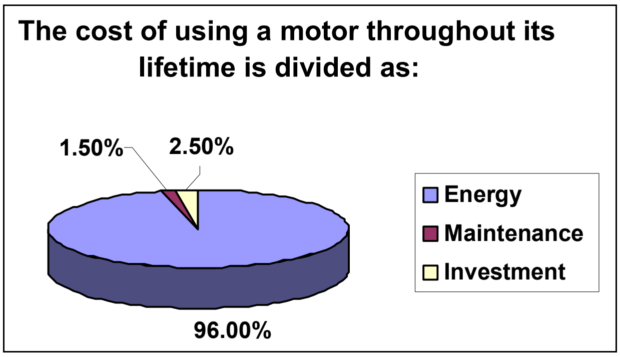

**Figure 3.25: Lifetime cost of an electric motor**

When buying a motor it is really important to consider the energy consumption and to minimise it:

- payback period can be as short as one year or less with AC drives
- high efficiency motors need a longer payback on energy savings.

**Driving forces for implementation**
AC drives are often installed in order to improve the machine control.
Other factors are important in the selection of motors: e.g. safety, quality and reliability, reactive power, maintenance interval.

**Examples**

- LKAB (Sweden) – the mining company, consumes 1700 gigawatt hours of electricity a year, 90 per cent of which is used to power 15 000 motors. By switching to high efficiency motors, LKAB cut its annual energy bill by several hundred thousand dollars (no date)
- Heinz food processing factory (UK) – a new energy centre will be 14 % more efficient due to combustion air fans controlled by AC drives. The energy centre has four boilers and has replaced the existing boiler plant.

**Reference information**

[137, EC, , 139, US_DOE]

## 3.7 Compressed air systems (CAS)

[168, PNEUROP, 2007, 169, EC, 1993, 194, ADEME, 2007] [189, Radgen&Blaustein, 2001, 196, Wikipedia]

**Description**

Compressed air is air that is stored and used at a pressure higher than atmospheric pressure. Compressed air systems take a given mass of air, which occupies a given volume of space, and compress it into a smaller space.

Compressed air accounts for as much as 10 % of industrial consumption of electricity, or over 80 TWh per year in the EU-15.

Compressed air is used in two ways:

- as an integral component in the industrial process, e.g.
  - providing low purity nitrogen to provide an inert process atmosphere
  - providing low purity oxygen in oxidation processes, e.g. waste water treatment
  - protection against contaminants, clean rooms, etc.
- as an energy medium, e.g.
  - stirring in high temperature processes, e.g. steel, and glass
  - blowing glass fibres and glass containers
  - plastics moulding
  - carrying paint to a substrate
  - moving heavy loads, such as steel coils (minimises floor loadings, e.g. see both the FMP and STM BREF).

Compressed air is intrinsically safe, due to its low risk of ignition or explosion either directly or from parts retaining heat, and it is therefore widely used in hazardous areas in chemical and related industries. It does not require a 'return' pipe/cable (vs. electricity) and being a fluid system, it is efficient at the point of delivery and provides constant power at constant pressure (e.g. delivering high torque at low revolutions for drills, etc.). It is also easy to adapt to changing production requirements (often in high volume production situations), and can be used with its own pneumatic logic controls, and also can be readily installed (although these are being superseded as cheaper electronic controls become available).

One of the common features of compressed air is its cleanliness, so the predominant use of compressed air in IPPC applications is as an integrated part of the core process. The pressure, the compressed air purity and the demand profile are predetermined by the process itself.

Pneumatic mechanical devices are often used for short, fast, low-force linear movements or create high forces at low speed, such as driving assembly tools and processes (either manual or automated). Electric devices used for the same purpose are available: there are stroke magnets for short, fast movements and motors with threaded-rod-drives for high forces. However, pneumatic tools are convenient due to their low weight-to-power ratio which make them useful for long periods of time without overheating and with low maintenance costs.

The compressed air supply often represents an integral part of the plant design and has to be analysed in parallel with the overall compressed air requirements of the facility. In IPPC applications the CAS is an important energy user and the share of the total energy used in the facilities may vary between 5 and 25 %. Due to the interest in energy efficiency, manufacturers of compressors and related equipment have developed technologies and tools for the optimisation of existing CAS and for design of new and more efficient ones.

Today investment is governed by lifecycle-cost analyses, especially with the supply of a new CAS. Energy efficiency is considered a major parameter in CAS design, and there is still potential in the optimisation of existing CAS. The lifetime of a large compressor is estimated at 15 to 20 years. In this time the demand profile in a facility can change and may need to be re-assessed, and in addition to this, new technologies are becoming available to improve the energy efficiency of existing systems.

In general the choice of an energy medium (e.g. CAS) depends on many parameters of the application and has to be analysed case by case (see Section 2.2.2).

*Energy efficiency in CAS*

The utilisation efficiency of compressed air can be defined where it drives a machine, such as assembly tools. In such cases, the overall thermodynamic efficiency of a normally operated and maintained compressed air installation is low [194, ADEME, 2007]

production efficiency (motor, transmission, compression): approximately 0.55
system transport efficiency (losses from single and system loads, leaks): approximately 0.6
final use efficiency (motor, leaks, etc.): approximately 0.3

Overall efficiency: 0.55 x 0.6 x 0.3 = 0.1, or approximately 10 %

However, in most major process industry uses, it is hard to calculate the efficiency, e.g. blowing metals, glass and plastics, etc. It may be the only readily-available technology to deliver the energy in the form required (as in blowing molten solids). It is also used in a growing number of applications an integral part of complex processes.

The energy efficiency of a CAS is predetermined by the quality of planning, manufacturing and maintenance of the system.

The aim of an expert system design is to provide compressed air suitable for the needs of the application. A proper understanding of the application and the compressed air demand must be identified before the implementation of one or more of the energy efficiency techniques. It is sensible to embed these techniques in an energy management system where a reliable compressed air system audit is supported by good quality database (see Chapter 2).

In 2000 a study[i] was carried out under the European SAVE programme to analyse the energy efficiency potentials in CAS. Even though it covers all applications, and CAS in IPPC facilities may be larger than the average CAS in industry, it provides a good overview on the relevant measures for improving the energy efficiency of CAS.

A summary is given in Table 3.22:

| Energy savings measure | % applicability (1) | % gains (2) | Potential contribution (3) | Comments |
|---|---|---|---|---|
| **System installation or renewal** | | | | |
| Improvement of drives (high efficiency motors) | 25 % | 2 % | 0.5 % | Most cost effective in small (<10 kW) systems |
| Improvement of drives (Speed control) | 25 % | 15 % | 3.8 % | Applicable to variable load systems. In multi-machine installations, only one machine should be fitted with a variable speed drive. The estimated gain is for overall improvement of systems, be they mono or multi-machine. |
| Upgrading of compressor | 30 % | 7 % | 2.1 % | |
| Use of sophisticated control systems | 20 % | 12 % | 2.4 % | |
| Recovering waste heat for use in other functions | 20 % | 20 % | 4.0 % | Note that the gain is in terms of energy, not of electricity consumption, since electricity is converted to useful heat. |
| Improved cooling, drying and filtering | 10 % | 5 % | 0.5 % | This does not include more frequent filter replacement (see below) |
| Overall system design, including multi-pressure systems | 50 % | 9 % | 4.5 % | |
| Reducing frictional pressure losses (for example by increasing pipe diameter) | 50 % | 3 % | 1.5 % | |
| Optimising certain end use devises | 5 % | 40 % | 2.0 % | |
| **System operation and maintenance** | | | | |
| Reducing air leaks | 80 % | 20 % | 16.0 % | Largest potential gain |
| More frequent filter replacement | 40 % | 2 % | 0.8 % | |
| | | **TOTAL[9]** | **32.9 %** | |
| Table legend: (1) % of CAS where this measure is applicable and cost effective<br>(2) % reduction in annual energy consumption<br>(3) Potential contribution = Applicability * Reduction | | | | |

**Table 3.22: Energy saving measures in CAS**

### Achieved environmental benefits

The aim of most techniques used to design or to modify a CAS is an improvement of the energy efficiency of that system. Consequential benefits of improving energy efficiency of CAS may include reduction of noise emissions and use of cooling water. Life expectancy of CAS and compressors is relatively high, therefore the use of materials in replacement equipment is low.

### Cross-media effects

Emissions are limited to noise and oil mist. Other environmental impacts of CAS are minor in relation to the use of energy.

In most facilities, the CAS is an independent sub-system. Most of the possible modifications in these systems do not influence other systems or processes. Energy usage for CAS should be accounted for when used in other processes, see Section 1.3.

## Operational Data

*Components of a CAS*

CAS are a combination of four sub-systems independent of the application:

- compressed air generation
- compressed air storage
- compressed air treatment
- compressed air distribution.

In addition to this there are auxiliary systems such as heat recovery or condensate treatment.

Typical components of the subsystems are shown in Table 3.23:

| Generation | Storage | Treatment | Distribution | Auxiliary systems |
|---|---|---|---|---|
| Compressor | Receiver | Dryer | Piping | Heat recovery |
| Controller |  | Filter | Valves | Condensate drains |
| Cooler |  |  |  |  |

**Table 3.23: Typical components in a CAS**

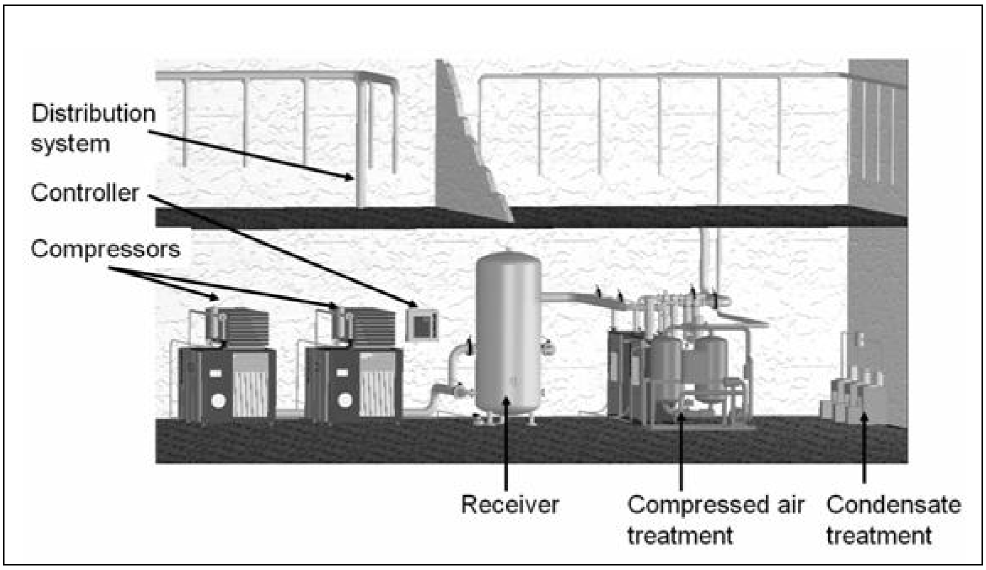

**Figure 3.26: Typical components of a compressed air system (CAS)**

The majority of the facilities have a multi compressor station with central compressed air treatment and a large distribution system. In addition to this; machines such as looms or glass manufacturing devices often have an integrated, dedicated compressed air system. There is no standard system design for specific applications. Depending on the process and the parameters, there is the need to select the right components and to manage their interaction.

*Type of compressors*

Efficiency varies with the type of the compressor and with design. Efficiency, and therefore, running costs are key factors in the selection of a compressor, but the choice may be determined by the required quality and quantity of the compressed air.

Currently, air compressor technology includes two basic groups, positive displacement and dynamic compressors. These are further segmented into several compressor types as shown in Figure 3.27.

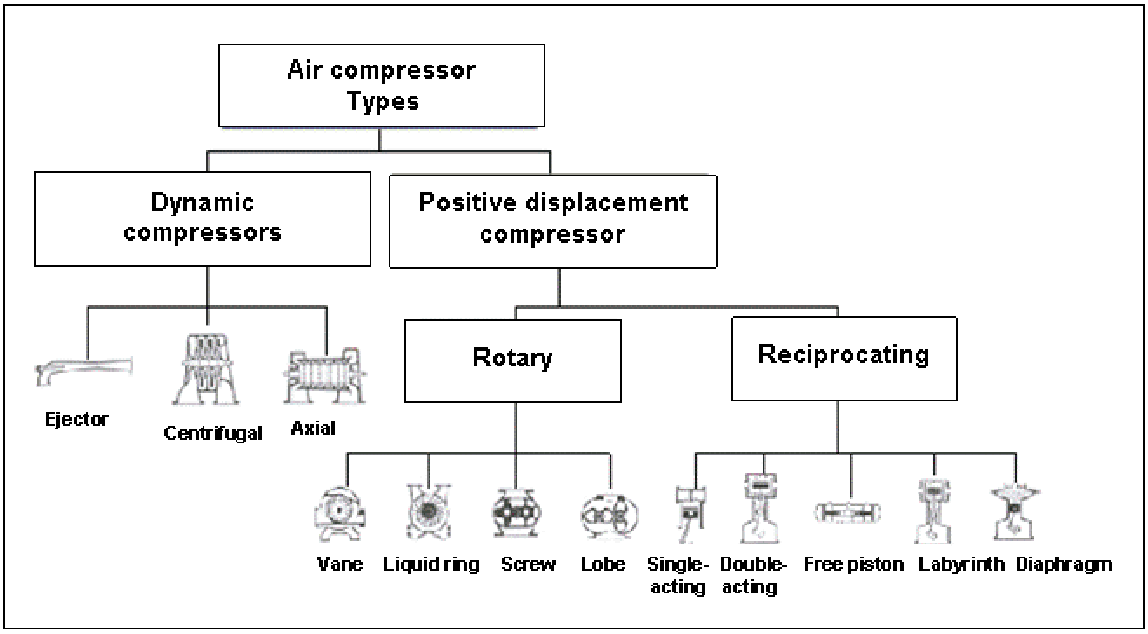

**Figure 3.27: Types of compressors**

- **Positive displacement** compressors increase the pressure of a given quantity of air by reducing the space occupied by the air at the original pressure. This type of compressor is available in two basic styles, reciprocating and rotary. Each of these basic styles is then further segmented by different technologies
    - *Reciprocating compressors* utilise a piston moving within a cylinder to compress low pressure air to high pressure. They are available in single-acting and double-acting configurations
    - *Rotary screw compressors* are the most widely applied industrial compressors in the 40 (30kW) to 500 hp (373 kW) range. They are available in both lubricated and oil-free configurations. The popularity of rotary compressors is due to the relatively simple design, ease of installation, low routine maintenance requirements, ease of maintenance, long operating life and affordable cost
- **Dynamic compressor** are rotary continuous-flow machines in which the rapidly rotating element accelerates the air as it passes through the element, converting the velocity head into pressure, partially in the rotating element and partially in stationary diffuses or blades. The capacity of a dynamic compressor varies considerably with the working pressure.

### Applicability

Each CAS is a complex application that requires expertise in its design and the application of particular techniques. The design depends on many parameters such as:

- demand profile (including peak demand)
- compressed air quality needed
- pressure
- spatial constraints imposed by the building and/or plant.

As an example, ISO 8573-1 classifies CAS quality for three types of contaminants. There are several classes which show the wide spread of purity needed for any contaminant in different applications.

| | | |
|---|---|---|
| • solid particle | 8 | classes |
| • humidity and liquid water | 10 | classes |
| • total oil content | 5 | classes. |

In addition to this it is not possible to evaluate the application of energy efficiency techniques for completely different systems. This can be illustrated by two demand profiles as shown in Figure 3.28:

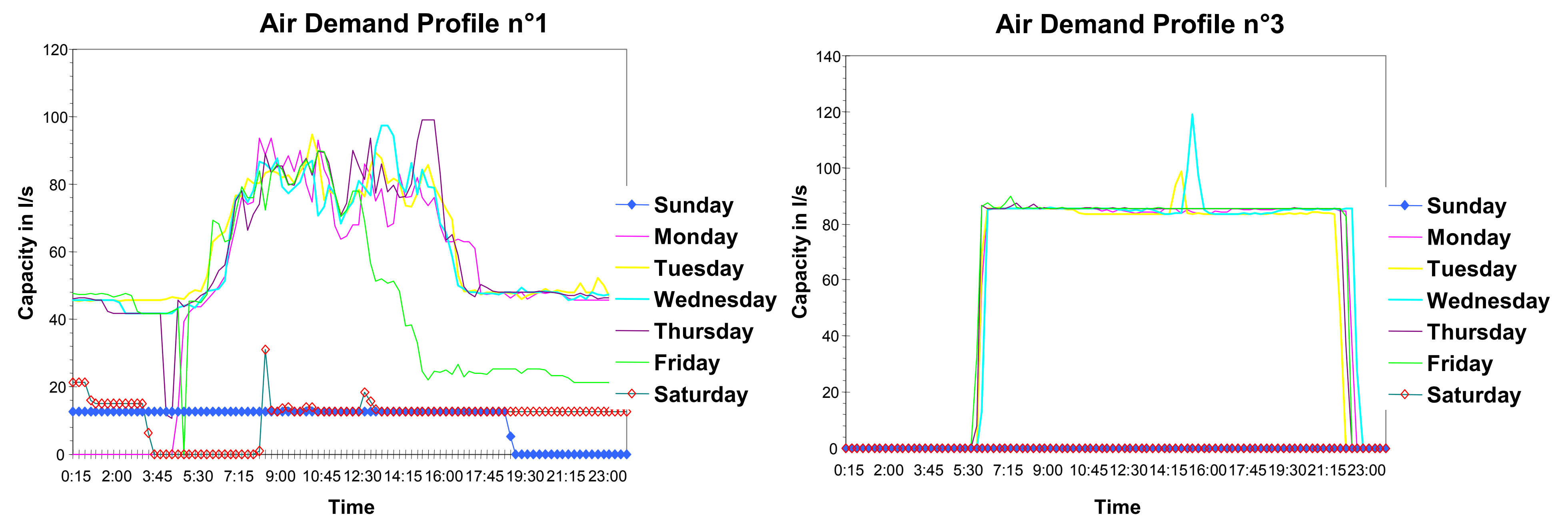

Figure 3.28: Different demand profiles

The description of the following techniques gives an impression of the possibilities. An expert system and demand analysis are the precondition for a new design or the optimisation of a CAS.

As described in Chapter 2, modifications in complex systems have to be evaluated case by case.

**Economics**

Compressed air price is very variable from one company to another, from EUR 0.006 to 0.03 per $Nm^3$. It is estimated that 75 % of this goes on energy compared with only 13 % on investment and 12 % on maintenance (based on usage of 6000 hours/year for five years). The variation in its cost is mainly due to the difference between an optimised installation and an installation that has not been optimised. It is essential to take this key parameter into consideration both when designing an installation and in the running of an existing installation.

The energy cost of compressed air is expressed in terms of specific energy consumption (SEC) in $Wh/Nm^3$. For a correctly dimensioned and well-managed installation, operating at a nominal flow and a pressure of 7 bars, the following can be taken as a reference (it takes different compressor technologies into account):

$$85\ Wh/Nm^3 < SEC < 130\ Wh/Nm^3$$ [194, ADEME, 2007]

This ratio represents the quality of the design and the management of the compressed air installation. It is important to know and monitor it (see benchmarking Section 2.12), because it can quickly deteriorate, leading to a large rise in the price of the air.

Initiatives have already been taken by Member State organisations and manufacturers in the area of energy efficiency improvement. Such programmes have shown that the implementation of the described techniques have a good return of investment.

**Driving force for implementation**

The improvement of energy efficiency in combination with short amortisation periods is the relevant motivation for the implementation of the described techniques (normal market forces).

**Examples**

Widely used.
(see Annexes)

**Reference information**

[190, Druckluft, , 191, Druckluft, , 193, Druckluft]

### 3.7.1 System design

**Description**

Nowadays many existing CAS lack an updated overall design. The implementation of additional compressors and various applications in several stages along the installation lifetime without a parallel redesign from the original system have frequently resulted in suboptimal performance of the CAS.

One fundamental parameter in CAS is the pressure value. A big range of pressure demands, depending on the application, usually sets up a trade-off between low pressures giving a higher energy efficiency and high pressures where smaller and cheaper devices can be used. The majority of consumers use a pressure of about 6 bar(g), but there are requirements for pressures of up to 13 bar(g). Often the pressure is chosen to meet the maximum pressure needed for all devices.

It is important to consider that too low a pressure will cause malfunctioning of some machines, while a pressure higher than necessary will not, but will result in reduced efficiency. In many cases, there is an 8 or 10 bar(g) system pressure, but most of the air is throttled to 6 bar(g) by pressure reducing valves.

State-of-the-art is choosing a pressure which satisfies 95 % of all needs and using a small pressure-increasing device for the rest (and trying to eliminate the devices needing more than 6 bar(g), or having two systems with a different pressure, one with higher pressure and one for 6.5 bar(g).

Another basic parameter is the choice of the storage volume. As compressed air demand typically comes from a lot of different devices, mostly working intermittently, there are fluctuations in air demand. A storage volume helps to reduce the pressure demand fluctuations and to fill short-timing peak demands.

Smoothed demand allows a steadier running of smaller compressors, with less idling time and thus less electric energy needed. Systems may have more than one air receiver. Strategically locating air receivers near sources of high short-timing demand can also be effective, meeting peak demand of devices and making it possible to lower system pressure.

A third fundamental design issue for a compressed air system is dimensioning the pipework and positioning the compressors. Any type of obstruction, restriction or roughness in the system will cause resistance to airflow and cause pressure drop, as will long pipe runs. In the distribution system, the highest pressure drops are usually found at the points of use, including undersized hoses, tubes, push-fit connectors, filters, regulators and lubricators. Also, the use of welded pipework may reduce the frictional losses.

Sometimes the air demand has grown 'organically' over the years and a former side branch of the pipework – with a small diameter – has to transfer a higher volume flow, resulting in pressure loss. In some cases, plant equipment is no longer used. Airflow to this unused equipment should be stopped as far back in the distribution system as possible without affecting operating equipment.

A properly designed system should have a pressure loss of less than 10 % of the compressor’s discharge pressure to the point of use. This can be reached by: regular pressure loss monitoring, selecting dryers, filters, hoses and push-fit connectors having a low pressure drop for the rated conditions, reducing the distance the air travels through the distribution system and recalculating the pipe diameters if there are new air demands.

What is often summed up under the point 'overall system design' is actually the design function of the use of compressed air. This can lead to an inappropriate use, for example over-pressurisation followed by expansion to reach the proper pressure, but these are rare. In industry nowadays most people are aware of compressed air as a significant cost factor.

### Achieved environmental benefits

Keeping up a compressed air system design as the state-of-the-art lowers electric energy consumption.

### Cross-media effects

### Operational data

Better efficiency may require more and better equipment (more and bigger tubes, filters, etc.).

### Applicability

There are many compressed air systems, with estimates as high as 50 % of all systems, that could be improved by a revision of their overall design, with a gain of 9 % by lowering the pressure and with better tank dimensioning (in 50 % of systems) and 3 % by lowering pipework pressure losses (in 50 % of systems) resulting in 6 % = 0.5 x (0.09 + 0.03) energy savings.

Inappropriate use of compressed air can be found in approximately 5 % of all systems, with some 40 % lower demand possible, resulting in 2 % = 0.05 x 0.4 energy savings.

### Economics and driving force for implementation

The costs of revising a compressed air system with consequent readjustment of pressure and renewing pipework is not easy to calculate and depends very much on the circumstances of the particular plant. The savings in a medium size system of 50 kW can be estimated to be:

50 kW x 3000 h/yr x 0.08 EUR/kW x 10 % = EUR 1200 EUR/yr

The costs for a major revision in such a system, adding a 90 litre tank near a critical consumer and a shut-off valve for a sparsely used branch, replacing 20 metres of pipework, 10 hoses and disconnectors is about EUR 2000, so the payback period is a profitable 1.7 years. Often the costs are lower, when only some pressure readjustment needs to be done, but in every case there has to be thorough considerations about the lowest tolerable pressure meeting the needs.

Economics are a driving force to revise compressed air systems. A major obstacle is a lack of knowledge and/or of skilled staff responsible for compressed air systems. Technical staff may be aware that the compressed air is expensive, but the inefficiencies are not readily obvious, and the operator may lack staff with sufficient in-depth experience.

Initiatives in many countries of the EU for spreading compressed air knowledge strongly promoted the implementation, creating a 'win-win-win' situation: the owner of the compressed air systems wins lower overall costs, the supplier of compressors and other devices wins higher revenues and the environment wins lower power station emissions.

### Examples

### Reference information

[168, PNEUROP, 2007, 194, ADEME, 2007]

### 3.7.2 Variable speed drivers (VSD)

**Description**

Variable speed drives (VSD, see Section 3.6) for compressors find applications mainly when the process air requirements of the users fluctuate, over times of the day and days of the week. Conventional compressor control systems such as load/unload, modulation, capacity control and others, try to follow this change in the air demand. If this leads to high switching frequencies and high idle time, a consequential reduction in the energy efficiency takes place. In VSD compressors the speed of the electric motor is varied in relation to the compressed air demands, resulting in a high level of energy saving.

Studies show that a majority of compressed air applications have moderate to large fluctuations in air demand and hence the potential for energy saving by the application of variable speed driven compressors is large.

**Achieved environmental benefits**

Savings in energy.

**Cross-media effects**

None

**Operational data**

Tests carried out by an independent laboratory have demonstrated large energy savings, when running against typical air demand patterns. Variable speed drives on compressors, apart from energy savings, also yield some additional benefits:

- pressure is very stable and this benefits operational process stability in some sensitive processes
- power factors are much higher than for conventional drives. This keeps reactive power low
- starting currents never exceed the full load currents of the motor. Users can, as a consequence, reduce the ratings of electrical components. Also where applicable, the users can avoid power penalties from utility companies by avoiding current peaks during start-up. Peak saving occurs automatically
- VSD technology provides a smooth start-up at low speeds eliminating current and torque peaks, thus reducing mechanical wear and electrical stress and extending the operating lifetime of the compressor
- the noise level is reduced as the compressor runs only when necessary.

**Applicability**

Variable speed drive compressors are appropriate for a number of operations in a wide range of industries, including metal, food, textile, pharmaceutical, chemical plants, etc. where there is a highly fluctuating demand pattern of compressed air. No real benefit can be achieved if the compressor operates continuously at its full capacity or close to it (see Examples, below).

VSD compressors may be applied into an existing compressed air installation. On the other hand, VSD controllers could be integrated into existing fixed speed compressors; however, better performances are obtained when the VSD controller and the motor are supplied in conjunction since they are matched to give the highest efficiency within the speed range.

Many CAS already have a variable speed driven compressor so the applicability across industry for additional variable speed compressors is some 25 %. The saving can be up to 30 %, although the average gain in a CAS, where one compressor with variable speed drive is added, is about 15 %. It is likely that more CAS can employ variable speed driven compressors to good advantage.

### Economics

Energy constitutes typically about 80 % of the life cycle costs of the compressor, the balance of 20 % comprises investments and maintenance. An installation, where (conservatively estimated) 15 % energy is saved owing to using variable speed drives, saves 12 % of life cycle costs, whereas the additional investment for the variable speed compressor (instead of a traditional one) adds only some 2 to 5 % to the life cycle costs.

### Driving force for implementation

Economics and environmental concerns are the primary drivers.

### Examples

Capacity tests to BS1571 were undertaken on an 18-month old screw compressor at Norwegian Talc Ltd. Hartlepool, UK. Energy savings of 9.4 kW (or 9 % of full-load power) at 50 % of rated delivery were possible, and greater savings were possible if running at even lighter load. However, at full-load the energy consumption would be 4 % higher due to the power losses with the inverter. Therefore, VSD should not be used with compressors running for long periods at full-load.

### Reference information

[168, PNEUROP, 2007, 194, ADEME, 2007, 195, DETR]

### 3.7.3 High efficiency motors (HEM)

**Description**

Although a formal definition for a high efficiency motor does not exist, these components are generally classified as motors where losses have been reduced to the absolute minimum. High efficiency motors minimise electrical and mechanical losses to provide energy savings. Various classifications exist worldwide to differentiate high efficiency motors from others. Examples are EFF1, NEMA premium, etc.

**Achieved environmental benefit**

Savings in energy.

**Cross-media effects**

- current drawn is lower
- heat generated is lower.

**Operational data**

**Applicability**

Motor losses are independent of where and what for the motor is used for. This means that high efficiency motors can be used almost anywhere. High efficiency motors are already used in most large applications (75 %); the majority of the remaining 25 % are smaller systems.

**Economics**

A seemingly small efficiency gain of even 1 – 2 % has a proportional saving during the entire lifetime of the motor. Cumulative savings will be substantial.

**Driving force for implementation**

Cost savings.

**Examples**

**Reference information**

[168, PNEUROP, 2007, 194, ADEME, 2007, 195, DETR]

### 3.7.4 CAS master control systems

**Description**

In the majority of IPPC applications, CAS are multi-compressor installations (see Section 3.1). The energy efficiency of such multi-compressor installations can be significantly improved by CAS master controls, which exchange operational data with the compressors and partly or fully control the operational modes of the individual compressors.

The efficiency of such master controls strongly depends on the capabilities of the communication link, which can range from simple floating relay contacts to networks using automation protocols. Increase in communication capabilities offers more degrees of freedom to retrieve operational data from the compressor, to control the operational mode of the individual compressors and to optimise the overall energy consumption of CAS.

The control strategy of the master control has to take into account the characteristics of the individual compressors, in particular their control mode. Some remarks on control modes of common compressor types are given to illustrate this. The most commonly used control modes of individual compressors are:

- switching between load, idle and stop, and
- frequency control.

The main features of sophisticated compressor and master controls can be summarised as follows:

- advanced communication features (e.g. based on automation protocols)
- comprehensive access of the CAS master control to operational data of individual compressors
- comprehensive control of all compressor operation modes by the CAS master control
- self-learning optimisation of master control strategy, including recognition of CAS properties
- determination and activation of highly energy efficient combinations of loaded, idling and stopped compressors and transitions between these states to match total FAD demand
- effective control of variable frequency compressors to compensate short term fluctuations in FAD demand avoiding inefficient long term operation at constant speed, in particular at low frequencies
- minimisation of switching frequencies and idle operation of fixed speed compressors
- sophisticated prediction methods and models for total FAD demand including recognition of cyclic demand patterns (daily or weekly shift and workspace patterns etc.)
- additional functions like remote monitoring, plant data collection, maintenance planning, teleservice and/or supply of preprocessed operational data via web-servers
- control of other CAS components in addition to compressors.

**Achieved environmental benefit**

- Improved energy efficiency.
- Current drawn and heat generated are lower.

**Cross-media effects**

None.

### Operational data

- *In single compressor installations*
  The optimal operating conditions in a CAS take place when the compressor works continuously at fixed speed at optimum efficiency. However, if the air demand is not continuous, stopping/idling the compressor during long off periods may be a more efficient solution.

  - **Compressors without frequency control** are switched between load, idle and stop to operate at fixed speed and provide 100 % free air delivery (FAD) during load and 0 % FAD during idle or stop. Sometimes, operating the compressor in idle mode instead of stopping it may be necessary, if the pressure regulation requires more frequent changes between 100 % FAD and 0 % FAD than the permissible starting frequency of the electric drive motor would allow for.

    The power consumption during idle operation is typically 20 – 25 % of the full load value. Additional losses result from venting the compressor after switching to stop and from electric starting losses of the drive motor. In single compressor installations the required switching frequency directly depends on the load profile, the receiver (storage) size, the admissible pressure band and the FAD of the compressor.

    If these control parameters are chosen inappropriately the average efficiency of fixed speed compressors operating in discontinuous mode can be significantly reduced compared to those operating full speed in continuous mode. In such cases, the use of sophisticated master controls to optimise the process parameters of the compressor working discontinuously is an effective tool to improve the efficiency of the CAS. Complex master controls are designed and programmed to minimise idle operation and switching frequencies using various strategies by directly stopping compressors whenever the motor temperature (measured or estimated) allows for a possible immediate restart, where necessary. Fixed speed compressors are very energy efficient if minimisation of idle periods is achieved.

  - In **compressors with frequency control** the operating speed of the compressor element is continuously varied between maximum and minimum speed. Normally the control range between maximum and minimum speed is approx. 4:1 to 5:1 and the FAD of displacement compressors (e.g. screw compressors) is roughly proportional to the operating speed. Due to inherent losses in frequency converters and induced losses in the asynchronous drive motors the efficiency of the drive system itself is reduced compared to fixed speed drives (3 – 4 % reduction at full load, and even more at part load). In addition, the efficiency rate of displacement compressors (e.g. oil-injected and dry running screw compressors) significantly decreases at low operating speeds compared to operation at the design point.

    In single compressor installations, these negative effects can be compensated by the appropriate regulation properties of the variable frequency compressor when eliminating the idling, venting and/or starting losses that fixed speed compressors would have in the same application. Due to the limited control range (see above) even variable frequency compressors have some idling, stopping and/or starting losses at low FAD demand.

- *Multi-compressor installations*
  The above reasoning is too simplistic because the varying overall FAD demand will be matched by the master control through complex combinations of, and transitions between, the operation modes of several compressors. This also includes controlling the operating speed of a variable frequency compressor, where there are any, in order to significantly minimise the idle operation and switching frequencies of the fixed speed compressors.

  This can be very successful in CAS with relatively low storage capacity, strongly and/or rapidly varying FAD demand, few compressors and/or insufficiently staged compressors sizes. CAS with reasonably staged compressor sizes on the other hand enable master controls to precisely adjust produced FAD to FAD demand by activating a multitude of different compressor combinations with low switching frequencies and low idle time.

  Master controls typically operate multiple compressors on a common pressure band to keep a defined minimum pressure at an appropriate measurement point. This provides clear energy savings compared to cascade schemes. Sophisticated master controls use strategies which allow narrowing of the pressure band without increasing the switching frequencies and the idle time of the compressors. A narrow pressure band further lowers the average back-pressure and hence reduces the specific energy requirement of the loaded compressors and artificial downstream demand.

**Applicability**
According to the SAVE study, the retrofit of sophisticated control systems is applicable to, and cost effective for, 20 % of existing CAS. For typically large CAS in IPPC installations the use of sophisticated master controls should be regarded as state-of-the-art.

The highest energy savings can be achieved if the implementation of sophisticated master controls is planned in the phase of system design together with initial compressor selection or in combination with major component (compressors) replacements. In these cases attention should be paid to the selection of master and compressor controls with advanced, comprehensive and compatible communication capabilities.

Due to the long lifetime of CAS this optimum scenario is not always within reach, but retrofitting existing CAS with sophisticated master controls and – if there is no more progressive alternative – even connecting old compressors to it via floating relay contacts can provide significant energy savings.

**Economics**
The cost effectiveness for integrating master control systems in newly designed CAS depends on circumstances like demand profiles, cable lengths and compressor types. The resulting average energy saving is estimated to be 12 %. In the case of retrofitting a master control system in existing CAS, the integration of older compressors and the availability of plans gives another uncertainty, but a payback time of less than one year is typical.

**Driving force for implementation**
The primary driving force for implementation is the reduction of energy costs, but some others are worth mentioning. If sophisticated master and compressor controls provide advanced communication capabilities it becomes possible to collect comprehensive operational data in the master control. In combination with other features this provides a basis for planned or condition-based maintenance, teleservice, remote-monitoring, plant data collection, CA costing and similar services, which contribute to a reduction of maintenance costs, an increase of operational availability and a higher awareness of CA production costs.

**Examples**

The installation of a computerised compressor control system has reduced compressed air generation costs by 18.5 % at Ford Motor Company (former Land Rover) Solihull, UK. The system was installed and has been operated with no disruption to production. The overall costs for the system produced a payback period of 16 months which could be replicated on most compressed air systems utilising three or more compressors. This presents a simple and reliable opportunity for large compressed air users to reduce their electrical costs as shown below:

- potential users: any compressor house containing three or more compressors
- investment costs (1991): total system-related costs were GBP 31700, of which GBP 20000 were capital costs (1991 prices) EUR conversion
- savings achieved: 600000 kWh (2100 GJ/year, worth GBP 24000/year (1991 prices)
- payback period: 1.3 years (direct benefit from controller); eight months (taking into account consequent leakage reduction).

The required investment costs have fallen significantly nowadays, thus the capital cost would have reduced from GBP 20000 to GBP 3573 in 1998 resulting in a payback of less than 3 months despite the lower cost of electricity to Land Rover in 1998.

**Reference information**

[113, Best practice programme, 1996]

### 3.7.5 Heat Recovery

**Description**

Most of the electrical energy used by an industrial air compressor is converted into heat and has to be conducted outwards. In many cases, a properly designed heat recovery unit can recover a high percentage of this available thermal energy and put it into useful work heating air or water.

**Achieved environmental benefits**

Energy saving.

**Cross-media effects**

None.

**Operational data**

Two different recovery systems are available:

- Heating air:

  Air-cooled packaged compressors are suitable to heat recovery for space heating, industrial drying, preheating aspirated air for oil burners or any other applications requiring warm air. Ambient atmospheric air is passed through the compressor coolers where it extracts the heat from the compressed air process.

  Since packaged compressors are typically enclosed in cabinets and already include heat exchangers and fans, the only system modifications needed are the addition of ducting and another fan to handle the duct loading and to eliminate any back pressure on the compressor cooling fan. These heat recovery systems can be modulated with a simple thermostatically-controlled hinged vent.

Heat recovery for space heating is less efficient for water-cooled compressors because an extra stage of heat exchange is required and the temperature of the available heat is lower. Since many water-cooled compressors are quite large, heat recovery for space heating can be an attractive opportunity.

- Heating water:

  It is also possible to use a heat exchanger to extract waste heat from the lubricant coolers found in packaged air- and water-cooled compressors to produce hot water. Depending on design, heat exchangers can produce non-potable or potable water. When hot water is not required, the lubricant is routed to the standard lubricant cooler.

  Hot water can be used in central heating or boiler systems, shower systems, industrial cleaning processes, plating operations, heat pumps, laundries or any other application where hot water is required.

**Applicability**

Heat recovery systems are available for most compressors on the market as optional equipment, either integrated in the compressor package or as an external solution. For existing CAS it can generally be retrofitted very easily and economically. Heat recovery systems are applicable for both air and water-cooled compressors.

**Economics**

As much as 80 – 95 % of the electrical energy used by an industrial air compressor is converted into thermal energy. In many cases, a properly designed heat recovery unit can recover approximately 50 – 90 % of this available thermal energy and put it into useful work heating air or water.

The potential energy savings are dependent on the compressed air system, on the operating conditions and on the utilisation.

Recoverable heat from a compressed air system is normally insufficient to be used to produce steam directly.

Typical air temperatures of 25 to 40°C above the cooling air inlet temperature and water temperatures of 50 to 75°C can be obtained.

An example for an energy saving calculation of an oil injected screw compressor is given in Table 3.24 below:

| **Nominal power compressor** | **Recoverable heat** (approx. 80 % of nominal power) | **Annual fuel oil saving** at 4000 running hours/yr | **Annual cost saving** @ EUR 0.50 EUR/L fuel oil |
|---|---|---|---|
| kW | kW | Litres/yr | EUR /yr |
| 90 | 72 | 36330 | 18165 |

**Table 3.24: Example cost saving**

$$\text{Annual Cost Saving}\,[\text{Euro}/a] = \frac{\text{Nominal Power Compressor}\,[kW] \times 0{,}8 \times \text{Running Hours}/a \times \text{Fuel Oil Costs}\,[€/L]}{\text{Gross Calorific Value Fuel Oil}\,[kWh/L] \times \text{Heating Oil Efficiency Factor}}$$

- gross caloric value fuel oil: = 10.57 (kWh/l)
- efficiency factor oil heating: = 75 %.

**Driving force for implementation**

Cost saving.

**Examples**

**Reference information**

[121, Caddet Energy Efficiency, 1999, 168, PNEUROP, 2007]

### 3.7.6 Reducing compressed air system leaks

**Description**

The reduction of compressed air system (CAS) leaks has by far the highest potential gain on energy. Leakage is directly proportional to the system pressure (gauge). Leakages are present in every CAS and they are effective 24 hours a day, not only during production.

The percentage of compressor capacity lost to leakage should be less than 10 % in a well-maintained large system. For small systems, leakage rates of less than 5 % are recommended. The amount of leakage in a poorly-maintained 'historically grown' CAS can be up to 25 %.

Preventive maintenance programs for compressed air systems should therefore include leak prevention measures and periodic leak tests. Once the leaks are found and repaired, the system should be re-evaluated.

- Estimating the amount of leakage:

All methods of estimating the amount of leakage in a CAS require that there are no demands on the system, which means that all air-consuming devices are turned off and therefore all air consumption is only due to leakage:

- direct measurement is possible if a compressed air consumption measurement device is installed
- in CAS with compressors that use start/stop controls, the estimation of the amount of leakage is possible by determination of the running time (on-load time) of the compressor in relation to the total time of the measurement. In order to get a representative value, the measurement time should include at least five starts of the compressor. Leakage expressed as a percentage of the compressor capacity than calculates as follows:

  Leakage (%) = 100 x running time / measurement time

- In CAS with other control strategies, leakage can be estimated if a valve is installed between the compressor and the system. An estimation of the total system volume downstream of that valve and a pressure gauge downstream of the valve are also required.

  The system is then brought to operating pressure (P1), the compressor is switched off and the valve shut. The time (t) it takes for the system to drop from P1 to a lower pressure P2 is measured. P2 should be about 50 % of the operating pressure. The leakage flow can then be calculated as follows:

Leakage ($m^3$/min) = system volume ($m^3$) x (P1 (bar) - P2 (bar)) x 1.25 / t (min)

`

The 1.25 multiplier is a correction for the reduced leakage with falling system pressure.
Leakage expressed as a percentage of the compressor capacity than calculates as follows:

Leakage (%) = 100 x Leakage ($m^3$/min) / compressor inlet volume flow ($m^3$/min)

- Leakage reduction:

Stopping leaks can be as simple as tightening a connection or as complex as replacing faulty equipment such as couplings, fittings, pipe sections, hoses, joints, drains, and traps. In many cases, leaks are caused by bad or improperly applied thread sealant. Equipment or whole parts of the system no longer in use should be isolated from the active part of the CAS.

An additional way to reduce leakage is to lower the operating pressure of the system. With lower differential pressure across a leak, the leakage flowrate is reduced.

**Achieved environmental benefits**
Energy savings.

In addition to being a source of wasted energy, leaks can also contribute to other operating losses. Leaks cause a drop in system pressure, which can make air tools function less efficiently, which decreases productivity. In addition, by forcing the equipment to cycle more frequently, leaks shorten the life of almost all system equipment (including the compressor package itself). Increased running time can also lead to additional maintenance requirements and increased unscheduled downtime. Finally, air leaks can lead to adding unnecessary compressor capacity.

**Cross-media effects**
None reported.

**Operational data**
Leaks are a significant source of wasted energy in an industrial compressed air system, sometimes wasting 20 – 30 % of a compressor's output. A typical plant that has not been well maintained will likely have a leak rate equal to 20 % of total compressed air production capacity.

On the other hand, proactive leak detection and repair can reduce leakage to less than 10 % of compressor output, even in larger CAS.

- Leak detection:

Several methods exist for leak detection:
  - searching for audible noise caused by larger leaks
  - applying soapy water with a paint brush to suspect areas
  - ultrasonic acoustic detector
  - tracer gas leak detection using e.g. hydrogen or helium.

- Typical leak locations:

While leakage can occur in any part of the system, the most common problem areas are:
    - couplings, hoses, tubes, and fittings
    - pressure regulators
    - open condensate traps and shut-off valves
    - pipe joints, disconnects, and thread sealants
    - compressed air tools.

### Applicability

Generally applicable to all CAS. (see table 3.20)

### Economics

The costs of leak detection and repair depend on the individual CAS and on the expertise of the maintenance crew of the plant (see Section 3.6.4, paragraph 2 and 3). A typical saving in a medium size CAS of 50 kW is:

50 kW x 3000 h/yr x EUR 0.08/kWh x 20 % = EUR 2400/yr

The typical costs for regular leakage detection and repair is EUR 1000/yr

As leakage reduction is widely applicable (80 %) and gives the highest gains (20 %) it is the most important measure to reduce CAS energy consumption.

### Driving force for implementation

### Examples plant

Based on 1994 data, Van Leer (UK) Ltd used 179 kWh to produce 1000 $m^3$ of compressed air, at a cost of GBP 5.37/1000 $m^3$. The leakage reduction exercise resulted in annual energy savings of 189200 kWh worth GBP 5676/year. This represents a 25 % saving on the cost of providing compressed air. The leakage survey cost GBP 1700 and a further GBP 2186 (including replacement parts and labour) was spent on remedial work. With savings of GBP 5676/year, the leakage reduction programme achieved a payback period of nine months.

### Reference information

[168, PNEUROP, 2007]

### 3.7.7 Filter maintenance

**Description**

Pressure losses can be caused by badly maintained filters, either through inadequate cleaning or disposable filters not being replaced frequently enough.

**Achieved environmental benefits**

Energy saving. Reduced emissions of oil mist and/or particles.

**Cross-media effects**

Increased use of filters, and discarding as waste.

**Operational data**

**Applicability**

All CAS.

**Economics**

See Table 3.20.

**Driving force for implementation**

**Examples**

**Reference information**

## 3.8 Pumping systems

**Description**

Pumping systems account for nearly 20 % of the world's electrical energy demand and range from 25 to 50 % of the energy usage in certain industrial plant operations. Pumping systems are widespread in different usage such as:

- Industrial services, e.g.
    - food processing
    - chemicals
    - petrochemical
    - pharmaceutical
- commercial and agricultural services
- municipal water/waste water services
- domestic applications.

Pumps fall into two major groups described by the method for moving a fluid: *rotodynamic* pumps and *positive displacement* pumps. In industry, the majority are driven by electric motors but they can be driven by steam turbines in large industrial applications (or even by stand-alone reciprocating engines).

*Rotodynamic* pumps (usually centrifugal) are based on bladed impellors which rotate within the fluid to impart a tangential acceleration to the fluid and a consequent increase in the energy of the fluid. The purpose of the pump is to convert this energy into pressure energy of the fluid to be used in the associated piping system. After motors, centrifugal pumps are arguably the most common machine in the world, and they are a significant user of energy.

*Positive displacement* pumps cause a liquid to move by trapping a fixed amount of fluid and then forcing (displacing) that trapped volume into the discharge pipe. Positive displacement pumps can be further classified as either:

- a rotary type (e.g. the rotary vane pump). Common uses of vane pumps include high pressure hydraulic pumps, and in low vacuum applications, including evacuating refrigerant lines in air conditioners
- a reciprocating type (e.g. the diaphragm pump). Diaphragm pumps have good suction lift characteristics, some are low pressure pumps with low flowrates. They have good dry running characteristics and are low shear pumps (i.e. do not break up solids particles). They can handle high solid content liquids, such as sludges and slurries even with a high grit content. Diaphragm pumps with teflon diaphragms, ball check valves, and hydraulic actuators are used to deliver precise volumes of chemical solutions at high pressures (as much as 350 bar) into industrial boilers or process vessels. Diaphragm pumps can be used to provide oil-free air for medical, pharmaceutical and food-related purposes.

The energy and materials used by a pumping system depend on the design of the pump, the design of the installation and the way the system is operated. Centrifugal pumps are generally the cheapest option. Pumps may be used as single-stage, or multi-stage, e.g. to achieve higher/lower pressures. They are often paired as duty and standby pumps in critical applications.

**Achieved environmental benefits**

Some studies have shown that 30 to 50 % of the energy consumed by pump systems could be saved through equipment or control system changes.

**Cross-media effects**

None reported.

## Operational data

The first step towards identifying applicable energy savings measures and optimising a pumping system is to establish an inventory of the pumping systems in the installation with the key operating characteristics The inventory can be established in two phases (see Sections 2.8, 2.7.4 and Annex 6):

- basic system description:

This consists of consulting company records or carrying out simple measurements, in order to assemble the following data:

- list of, e.g. the 50 largest pumps (by total pump power rating): size and type
- function of these systems
- power consumption of each of these pumps
- demand profile: estimated variation during day/week
- type of control system
- operating hours/year, and hence annual energy consumption
- problems or maintenance issues specific to the pump.

In many organisations, most or all of these data could be assembled by in-house staff.

- documentation and measurement of system operating parameters:

Documenting or measuring the following elements is desirable for all pumping systems, and essential for large systems (over 100 kW). Collection of these data will require a significant level of technical expertise, either from in-house engineering staff or from a third party.

Because of the large variety of pumping systems, it is not possible to give a definitive list of points to look for in the assessment, but the following is a useful list of key issues to address.

○ pump selection

The pump is the heart of the pumping system. Its choice is driven by the need of the process which could be, first of all, a static head and a flowrate. The choice also depends on the system, the liquid, the characteristic of the atmosphere, etc…

In order to obtain an efficient pumping system, the choice of the pump has to be done so as to have an operating point as close as possible to the best efficiency point as indicated in Figure 3.29.

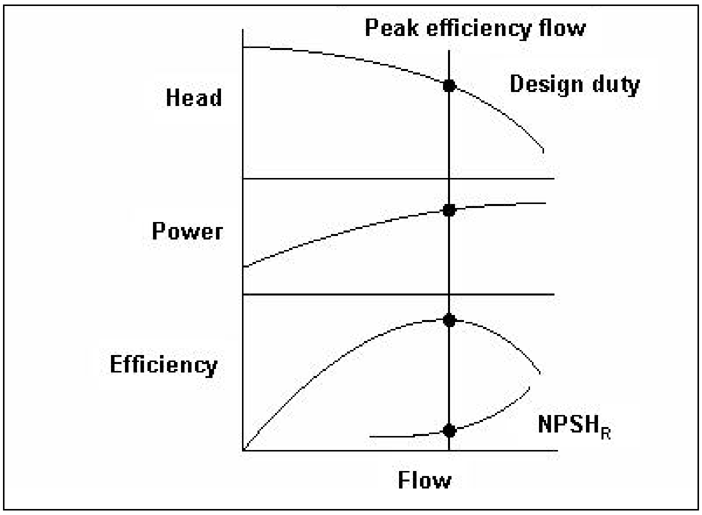

**Figure 3.29: Peak efficiency flow vs. head, power and efficiency**

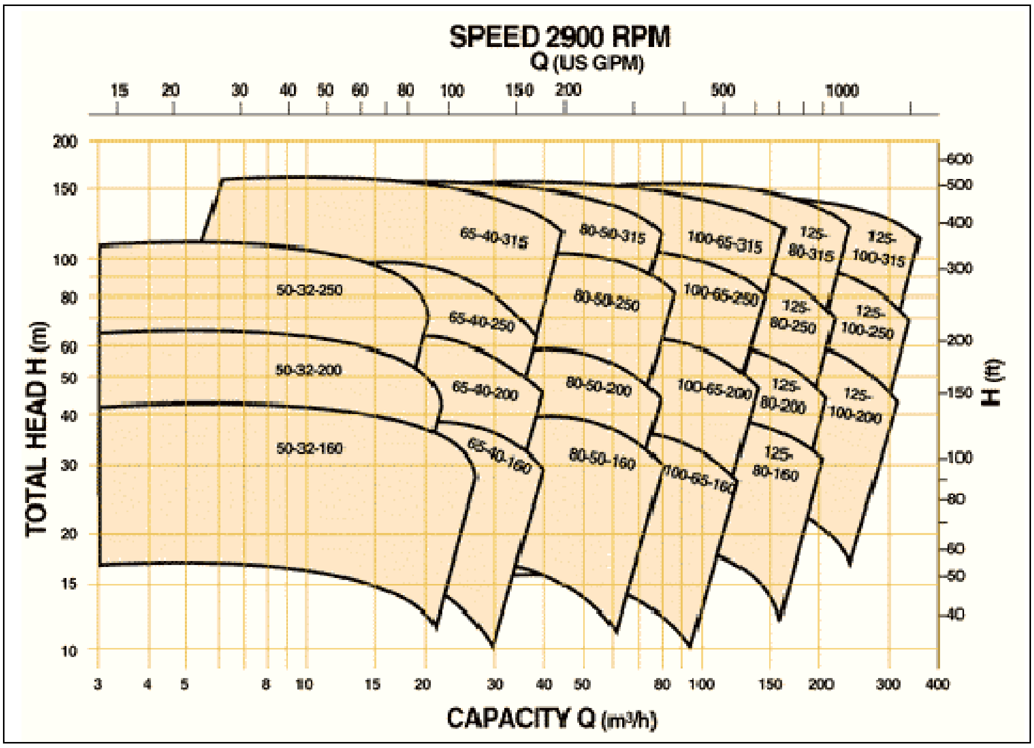

**Figure 3.30: Pump capacity vs. head**

It is estimated that 75 % of pump systems are oversized, many by more than 20 %. Oversized pumps represent the largest single source of wasted pump energy, because more flow is pumped at a higher pressure than required.

When choosing a pump, oversizing is neither cost nor energy effective as:

- the capital cost is high
- the energy cost is high because more flow is pumped at a higher pressure than required. Energy is wasted from excessive throttling, large bypassed flows, or operation of unneeded pumps.

Where oversized pumps are identified, their replacement must be evaluated in relation to other possible methods to reduce capacity, such as trimming or changing impellers and/or using variable speed controls. Trimming centrifugal pump impellers is the lowest cost method to correct oversized pumps. The head can be reduced 10 to 50 per cent by trimming or changing the pump impeller diameter within the vendor’s recommended size limits for the pump casing.

The energy requirements of the overall system can be reduced by the use of a booster pump to provide the high pressure flow to a selected user and allow the remainder of the system to operate a lower pressure and reduced power.

○ pipework system

The pipework system determines the choice of the pump performance. Indeed, its characteristics have to be combined with those of the pumps to obtain the required performance of the pumping installation as shown in the Figure 3.31 below.

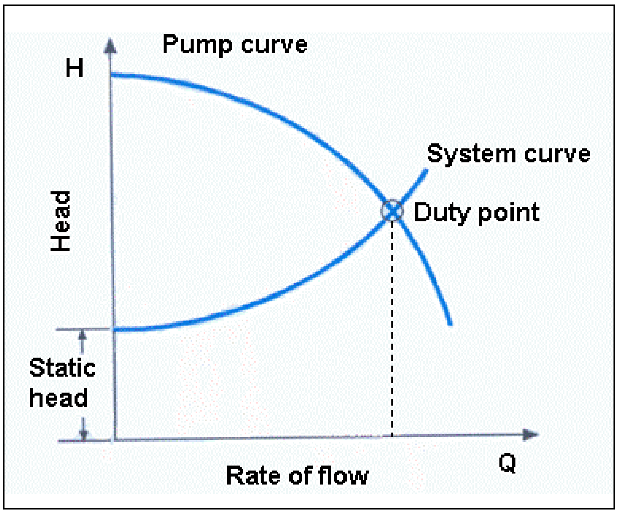

**Figure 3.31: Pump head versus flowrate**

The energy consumption directly connected to the piping system is the consequence of the friction loss on the liquid being moved, in pipes, valves, and other equipment in the system. This loss is proportional to the square of the flowrate.
Friction loss can be minimised by:

- avoiding the use of too many valves
- avoiding the use of too many bends (especially tight bends) in the piping system
- ensuring the pipework diameter is not too small.

○ maintenance
Excessive pump maintenance can indicate:

- pumps are cavitating
- badly worn pumps
- pumps that are misapplied for the present operation.

Pumps throttled at a constant head and flow indicate excess capacity. The pressure drop across a control valve represents wasted energy, which is proportional to the pressure drop and flow.

A noisy pump generally indicates cavitation from heavy throttling or excess flow. Noisy control valves or bypass valves usually mean a high pressure drop with a corresponding high energy loss.

Pump performance and efficiency deteriorates over time. Pump capacity and efficiency are reduced as internal leakage increases due to excessive clearances between worn pump components: backplate; impeller; throat bushings; rings; sleeve bearings. A condition monitoring test can detect this condition and help size a smaller impeller, either new, or by machining the initial one, to achieve great energy reduction. Internal clearances should be restored if performance changes significantly.

Applying coatings to the pump, particularly the volute, will reduce friction losses.

- pumping system control and regulation

A pump application might need to cover several duty points, of which the largest flow and/or head will determine the rated duty for the pump. A control and regulation system is important in a pumping system so as to obtain optimise the duty working conditions for the head pressure and the flow. It provides:

- process control
- better system reliability
- energy savings.

For any pump with large flow or pressure variations. When normal flows or pressures are less than 75 % of their maximum, energy is probably being wasted from excessive throttling, large bypassed flows (either from a control systems or deadhead protection orifices), or operation of unneeded pumps.

The following control techniques may be used:

- shut down unnecessary pumps. This obvious but frequently overlooked measure can be carried out after a significant reduction in the plant's use of water or other pumped fluid (hence the need to assess the whole system)
- variable speed drives (on the electric motor) yield the maximum savings in matching pump output to varying system requirements, but they do have a higher investment cost compared to the other methods of capacity control. They are not applicable in all situations, e.g. where loads are constant (see Section 3.6)
- multiple pumps offer an alternative to variable speed, bypass, or throttle control. The savings result because one or more pumps can be shut down when the flow of the system is low, while the other pumps operate at high efficiency. Multiple small pumps should be considered when the pumping load is less than half the maximum single capacity. In multiple pump systems, energy is commonly lost from bypassing excess capacity, running unneeded pumps, maintaining excess pressure, or having a large flow increment between pumps
- controlling a centrifugal pump by throttling the pump discharge (using a valve) wastes energy. Throttle control is, however, generally less energy wasteful than two other widely used alternatives: no control and bypass control. Throttles can, therefore, represent a means to save pump energy, although not the optimum choice.

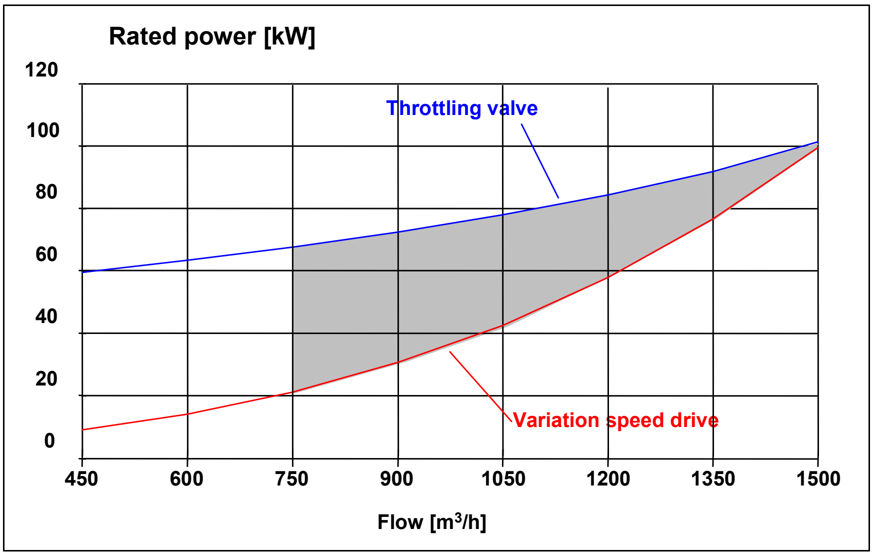

**Figure 3.32: Example of energy consumption for two pumping regulation systems for a rotodynamic pump**

- Motor and transmission

(See electrical motors, Section 3.6)

## Applicability

The applicability of particular measures, and the extent of cost savings depends upon the size and specific nature of the installation and system. Only an assessment of a system and the installation needs can determine which measures provide the correct cost-benefit. This could be done by a qualified pumping system service provider or by qualified in-house engineering staff.

The assessment conclusions will identify the measures that are applicable to a system, and will include an estimate of the savings, the cost of the measure, as well as the payback time.

## Economics

Pumping systems often have a lifespan of 15 to 20 years, so a consideration of lifetime costs against initial (purchase) costs are important.

Pumps are typically purchased as individual components, although they provide a service only when operating as part of the system, so a consideration of the system is important to enable a proper assessment of the cost-benefit.

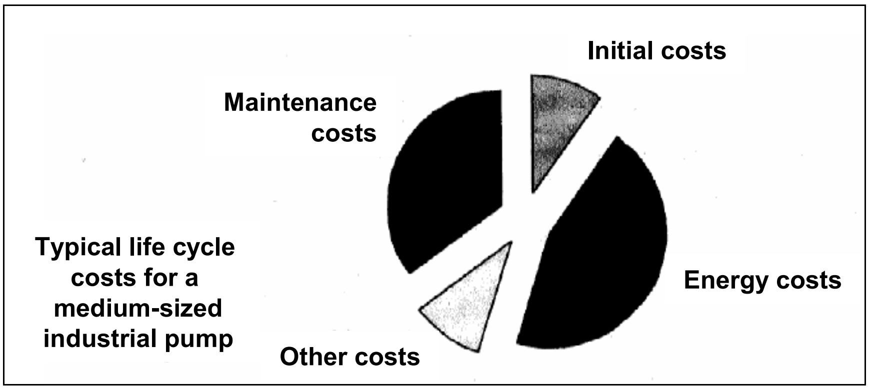

**Figure 3.33: Typical life cycle costs for a medium-sized industrial pump**

**Driving force for implementation**
Energy and cost savings

**Examples**
The optimisation techniques are widely used.

**Reference information**
[170, EC, 2003, 199, TWG, , 200, TWG]

## 3.9 Drying and separation processes

[26, Neisecke, 2003, 197, Wikipedia, , 201, Dresch, 2006]

Drying is a significant energy using process. It is considered here with separation techniques, as the use of different techniques or combinations offer energy savings.

Separation is a process which transforms a mixture into at least two streams (which may be product-product or product-waste streams) which are different in composition. The separation technology consists therefore in partitioning and isolating the wanted products from a mixture containing either different substances or a pure substance in several phases or sizes. Alternatively, it may be used to separate waste streams, see the CWW BREF).

The separation process takes place in a separation device with a separation gradient applied by a separating agent. In this section the separation methods have been classified according to the different principles of separation and separating agents used.

The purpose of this section is not to describe exhaustively every separation technique, but to focus mainly on those issues which have a higher potential for energy savings. For further details of a particular method, see the reference information.

*Classification of the separation methods*

- Input of energy into the system:
  detailed classification for these techniques can be structured considering the different types of energy provided to the system as listed below:
  - heat (vaporisation, sublimation, drying)
  - radiation
  - pressure (mechanical vapour recompression)
  - electricity (electrofiltration of gases, electrodialysis)
  - magnetism (use of magnets) (see ferrous & non-ferrous metals, EFS for non-metals)
  - kinetic (centrifugal separation) or potential energy (decantation)

- Withdrawal of energy out of the system
  - cooling or freezing (condensation, precipitation, crystallization, etc.)

- Mechanical barriers
  - filters or membranes (nano, ultra or microfiltration; gas permeation; sieving)

- Others
  - physico-chemical interactions (solution/precipitation, adsorption, flotation, chemical reactions)
  - differences in other physical or chemical properties of the substances such as density, polarity, etc.

Combination of the previously mentioned principles of separation or separating agents may be used in several processes leading to hybrid separating techniques. Examples are:

- distillation (vaporisation and condensation)
- pervaporation (vaporisation and membrane)
- electrodialysis (electric field and ion-exchange membrane)
- cyclonic separation (kinetic energy and potential energy).

### 3.9.1 Selecting the optimum separation technology

**Description**

Selecting a separation technology often has more than one solution. The election depends on the characteristics of the feed and the required outputs and other constraints linked to the type of plant and sector. The separation process also has its own constraints.

**Achieved environmental benefits**

Minimising energy usage.

**Cross-media effects**

None reported.

**Operational data**

Some factors related to either the feed material, the final product or the process which should be considered before selecting a separation technique, are:

- feed material
    - type, shape:
        - liquid
        - pasty
        - granular, powdery
        - fibrous
        - plane
        - belt
        - already in shape
    - mechanical fragility
    - thermosensitivity
    - moisture content
    - flowrate / quantity to be treated
    - if applicable
        - shape and size
        - size of droplets
        - viscosity

- final product specifications
    - moisture content
    - shape and size
    - quality
        - colour
        - oxidation
        - taste
- process
    - batch / continuous
    - heat sources:
        - fossil fuels (natural gas, fuel, coal, etc.)
        - electricity
        - renewable (solar, wood, etc.)
    - heat transfer through:
        - convection (hot air, superheated steam)
        - conduction
        - thermal radiation (radiant energies: infrared, microwaves, high frequency)
    - maximum temperature
    - capacity
    - residence time
    - mechanical action on the product.

A feasibility study is necessary to define the best solution(s) from a technical, economic, energy, and environmental point of view. Requirements should be precisely defined:

- feed and product parameters (mass and flow characteristics), especially the moisture content of the product: the last moisture percentages are usually the more difficult to dry and so are the most energy consuming
- list of all the utilities available (electricity, refrigeration, compressed air, steam, other cold or hot sources) and their characteristics
- available possible space
- possible pretreatment
- waste heat recovery potential of the process
- high energy efficiency utilities equipment and sources (high efficiency motors, use of waste heat, etc.).

A comparative analysis of the proposals has to be made on a technical, economic, energy, and environmental basis:

- within the same boundaries, including utilities, effluent treatment, etc.
- taking into account each environmental impact (air, water, waste, etc.)
- taking into account maintenance and security
- quantifing the time and cost of training of the operators.

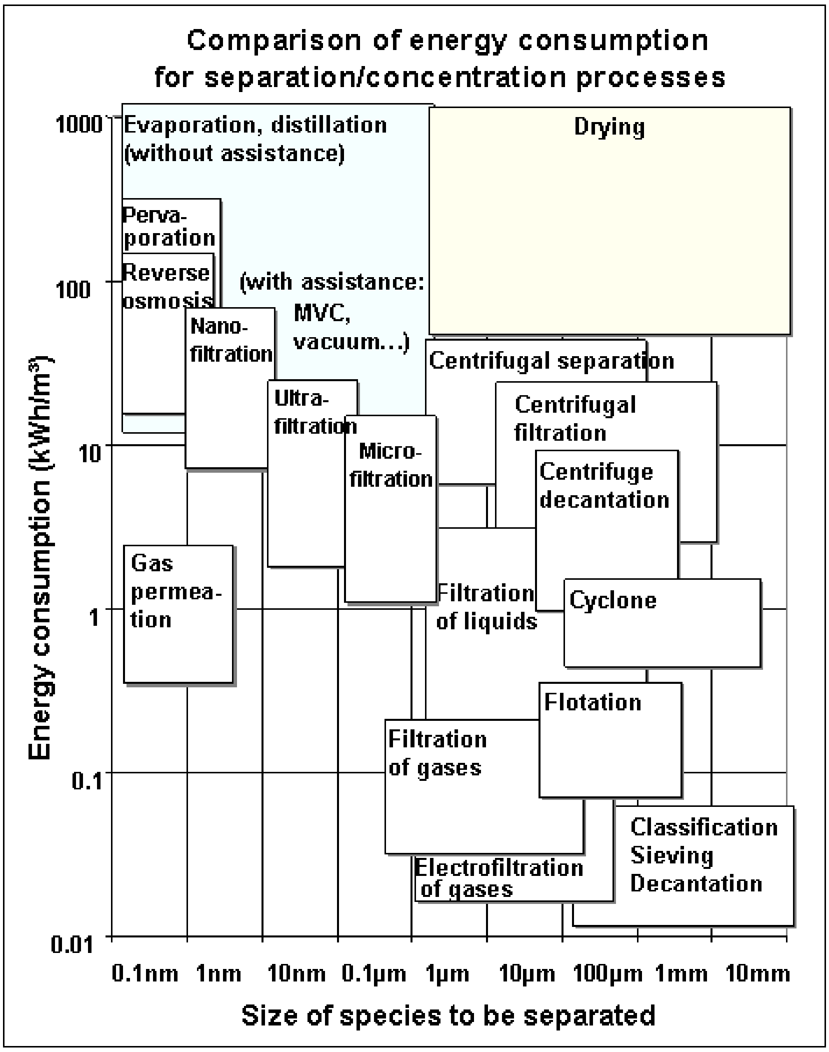

Figure 3.34: Energy consumption of some separation processes

**Applicability**

**Economics**

**Driving force for implementation**

**Examples**

**Reference information**
[201, Dresch, 2006]

## 3.9.2 Techniques to reduce energy consumption for drying and separation processes

### 3.9.2.1 Mechanical processes

**Description**
The energy consumption for mechanical processes can be several orders of magnitude lower compared to thermal drying processes, see Figure 3.34.

As long as the material to be dried lets it, it is recommendable to use predominantly mechanical primary separation processes to reduce the amount of energy used for the entire process. Generally speaking, the majority of products can be mechanically prehydrated to average moisture content levels (= ratio between the liquid mass of the liquid to be removed and the material's dry substance) of between on 40 and 70 per cent. In practice, the use of the mechanical process is limited by the permissible material loads and/or economic draining times.

Sometimes mechanical processes are also recommendable prior to thermal separation. When drying solutions or suspensions (spray drying for instance), the pretreatment can be membrane filtration (reverse osmosis, nanofiltration, ultrafiltration or microfiltration). For example, in the dairy industry, milk can be concentrated to 76 % moisture content before spray drying.

**Achieved environmental benefits**

**Cross-media effects**

**Operational data**

**Applicability**

**Economics**

**Driving force for implementation**

**Examples**

**Reference information**
[202, IFTS, 1999]

### 3.9.2.2 Thermal processes: drying

**Description**

Drying is a commonly used method in several industrial sectors.

In a dryer system, first of all the damp material is heated to the vaporisation temperature of water, then the water is evaporated at a constant temperature.

$$Q_{th} = (c_G m_G + c_W m_W)\,\Delta T + m_D \Delta H_V \qquad \text{Eq 4.9}$$

Where:

| | |
|---|---|
| $Q_{th}$ | useful output in kWh/h |
| $m_G$, $m_W$ | mass flows of dry matter and proportion of water in the material in kg/s |
| $\Delta T$ | heating temperature interval in K |
| $m_D$ | quantity of water evaporated per unit of time in kg/s |
| $c_G$, $c_W$ | specific heat capacities of dry matter and proportion of water in the material in kJ/(kg K) |
| $\Delta H_V$ | vaporisation heat of water at the respective evaporation temperature (approx. 2300 kJ/kg at 100 C). |

The vaporised water volume is generally removed using air from the drying chamber. The power demand $Q_{pd}$ required to heat the volume of fresh air (exclusively the useful heat output $Q_{th}$) can be calculated as shown in the following equation.

$$Q_{pd} = V_{Cpd} \Delta T_{pd} \qquad \text{Eq 4.10}$$

Where:

| | |
|---|---|
| $Q_{pd}$ | power demand required to heat the fresh air in kW/h (thermal exhaust losses) |
| V | flowrate of the fresh air in $m^3$/h |
| $c_{pd}$ | the air's specific heat capacity (approx. 1.2 kJ ($m^3$ K) at 20 C and 1013 mbar) |
| $\Delta T_{pd}$ | difference between the temperature of the fresh air and the exhaust air in Kelvin. |

The plant's heat losses (such as surface loss) must also be covered above and beyond this power demand. These system losses correspond to the holding power $Q_{hp}$ (power demand of the system when unloaded, at working temperature, and in recirculating air mode only). The entire heat requirement is shown in Eq 4.11.

$$Q_I = Q_{th} + Q_{pd} + Q_{hp} \qquad \text{Eq 4.11}$$

Where:

| | |
|---|---|
| $Q_I$ | power output required |
| $Q_{hp}$ | power demand for unloaded systems. |

The thermal efficiency of the firing ηfuel must be taken into account, depending on the firing equipment. This produces a consequent output $Q_{total}$ shown in Eq. 4.12

$$Q_{total} = Q_I/\eta_{fuel} \qquad \text{Eq. 4.12}$$

Where:

| | |
|---|---|
| $Q_{total}$ | total power output |
| $\eta_{fuel}$ | thermal efficiency. |

Figure 3.35 demonstrates the bandwidths for the specific secondary energy consumption per kilogram of evaporated water at maximum load and with maximum possible evaporation performance for various types of dryers. For the purposes of comparison, it has been assumed that the convection dryers use electrical resistance heating.

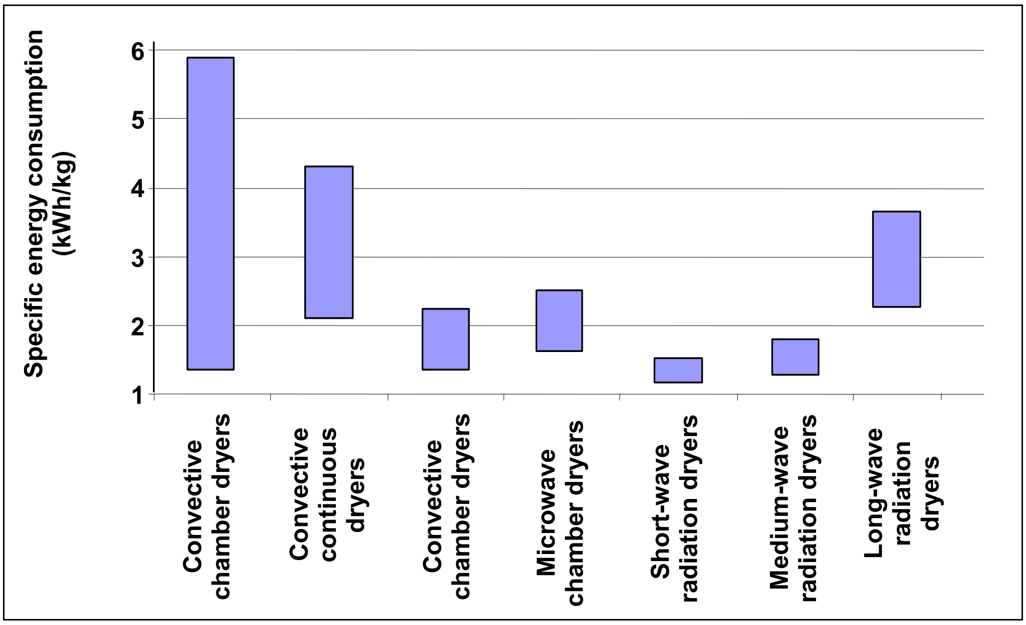

**Figure 3.35: Bandwidths for the specific secondary energy consumption of different types of dryer when vaporising water**
**[26, Neisecke, 2003]**

## Achieved environmental benefits

## Cross-media effects

## Operational data

## Applicability

## Economics

## Driving force for implementation

## Examples

## Reference information

[26, Neisecke, 2003, 203, ADEME, 2000]

### 3.9.2.3 Radiant energies

**Description**

In radiant energies such as infrared (IR), high frequency (HF) and microwaves (MW) energy is transferred by thermal radiation. Note that there is a difference between drying and curing: drying requires the raising of the solvent molecules to or above the latent heat of evaporation, whereas curing techniques provide the energy for cross-linking (polymerisation) or other reactions. The drying and curing of coatings is discussed in the STS BREF.

These technologies are applied in industrial production processes to heat products and thus, can be applied in drying processes. Radiant energies can be used alone or in combination with conduction or convection.

**Achieved environmental benefits**

Radiant energies have specific characteristics allowing energy savings in these processes:

- direct transfer of energy. Radiant energies allow direct transfer of energy from source to product, without using intermediate media. The heat transfer is thus optimum, especially by avoiding energy loss through ventilation systems. This can achieve significant energy savings. For example, for paint drying process, about 80 % of energy is extracted with the waste gases
- high power density. Surface (IR) or volume (HF, MW) power densities are higher for radiant energies compared to conventional technologies such as hot air convection. This leads to higher production velocity and allow treatment of high specific energy products such as powder paints *(that's curing, not drying/)*
- energy focusing. Energy can easily be focused on the required part of the product
- control flexibility. Thermal inertia is low with radiant energies and power variations are large. Flexible control can be used, which leads to energy savings and good quality manufactured products.

**Cross-media effects**

None reported.

**Operational data**

Exhaust airflow is generally far lower because air is not the intermediate medium for heat transfer but is just used to extract steam or other solvents. Treatment of exhaust gases, if applicable, is thus easier and less expensive.

One advantage is the control flexibility: thermal inertia is low with radiant energies and power variations are large. Flexible control can be set up, which leads to energy savings and good quality of manufactured products.

Other achieved benefits specific for IR:

- direct heating: reduction of hot air exhaust, thus energy saving; few or no hot fluid transport
- reduction of equipment size
- easier regulation
- retrofitting of plants.

Other achieved benefits specific for HF and MW:

- direct heating: reduction of hot air exhaust, thus energy saving; few or no hot fluid transport
- volume heating leads to rapid drying and less losses
- selective heating, water is heated preferentially
- homogeneous heating if the size of the products is compatible with wavelength
- efficient heat transfer.

Differential heating of heterogeneous products can occur and lead to poor quality products.

Some disadvantages for IR:

- larger investment (+20 – 30 %)
- essentially for flat or simple-shaped products
- often not the priority choice of constructors.

Some disadvantages for HF and MW:

- larger investment (+20 – 30 %)
- often not a priority choice of constructors.

**Applicability**
Radiant energies, in particular IR, can be used in retrofitting of installations or to boost the production line, coupled with convection or conduction.

In spite of their advantages (speed of action, quality of final products, energy savings), the use of radiant energies is not common in industrial applications, today known as having a great energy saving potential.

IR can be used in:

- curing of paint, ink and varnish
- drying of paper, paperboard, pre-drying of textiles
- drying powder in the chemical and plastics industries.

HF can be used in the drying of:

- massive (monolithic) products: textile (reels of wire), ceramics
- powder in the chemical industry.

MW can be used in drying of:

- massive (monolithic) products (wood, agro-industry) or flat products
- chemical and pharmaceutical products (under vacuum).

**Economics**
Investment is generally more expensive (+20 – 30 %) than conventional techniques.

**Driving force for implementation**
Radiant energies lead to compact systems. Lack of space availability can be a driving force.
They can be used to boost existing production lines, especially IR.

**Examples**

Biotex is a French plant producing latex pillows. Pillows are very difficult to dry and must have a moisture content of <1 % to avoid problems during usage. The convective tunnel (impinging jet) was not sufficient for a good quality and consumed a lot of energy. The implementation of an HF system at the output of the tunnel met the requirements in terms of quality and reduced the specific energy consumption per pillow by 41 % (primary energy) with a 8 fold reduction of production time. The convector tunnel leaves pillows with 19 to 45 % moisture, HF achieves 1 %. Payback time was 4 years.

**Reference information**

[204, CETIAT, 2002, 205, ADEME, , 206, ADEME, 2002]

### 3.9.2.4 Computer-aided process control/process automation in thermal drying processes

**Description**

In the vast majority of applications with thermal drying processes, dryers are normally controlled using target value specifications and/or predominantly empirical values (operator experience). The retention time, throughput speed, start moisture content, temperature and product quality are all used as control parameters. Moisture sensors with linear characteristics and low interferences, while still offering high service lives, are required to determine the moisture content. A computer can calculate these measurements in real time and compare them with target values calculated from the mathematical model of the drying process. This requires an exact knowledge of the drying process and suitable software. The controller changes the corresponding control variable by comparing the target and actual values.

Examples from different plants show that savings of between 5 and 10 % can be achieved compared with using traditional empirical controllers.

**Achieved environmental benefits**

**Cross-media effects**

**Operational data**

**Applicability**

**Economics**

**Driving force for implementation**

**Examples**

**Reference information**

[207, ADEME, 2000]

### 3.9.2.5 Superheated steam

**Description**

Superheated steam is steam heated to a temperature higher than the boiling point of water at a given pressure. It cannot exist in contact with water, nor contain water, and resembles a perfect gas; it is called also surcharged steam, anhydrous steam, and steam gas. Superheated steam can be used as a heating fluid instead of hot air in any direct dryers (where the heating fluid is in direct contact with the product); for example in spray drying, fluidised bed, spouted bed, drums, etc.

**Achieved environmental benefits**

The advantage is that the limiting phenomenon is only heat transfer and not mass (water) transfer. The drying kinetic is thus better. Dryers are smaller and thus so are heat losses. Moreover, the energy (latent heat) of the water coming from the product can easily be recycled in the dryer via a mechanical vapour recompression (MVR) or used in another process, increasing the energy savings.

Dealing with volatile organic compounds (VOCs) is easier because of the limited volume of exhaust gases. These compounds can be easily recovered.

**Cross-media effects**

Thermosensitive products can be damaged by the high temperature.

**Operational data**

Energy consumption is about 670 kWh/t evaporated water without heat recovery and 170 to 340 kWh/t with heat recovery (MVR for example).

Process control is easier because the final moisture of the product and drying kinetic can be controlled through steam temperature. Elimination of air reduces the risks of fire and explosion.

**Applicability**

Any direct dryers can be retrofitted with superheated steam. Tests should be conducted to guarantee the product quality, and economic calculations have to be made.

**Economics**

The investment is generally higher, especially when a MVR is used.

**Driving force for implementation**

Energy savings should be the first driving force for implementation. Better product quality is often reported, especially in agro-food industry (better colour, absence of oxidation, etc.).

**Examples**

Sucrerie Lesaffre (Nangis, France): drying of beet pulp using superheated steam
Applications: sludge, beet pulp, alfalfa, detergent, technical ceramics, wood-based fuel, etc.

**Reference information**

[208, Ali, 1996]

## 3.10 Ventilation

A ventilation system is essential for many industrial installations to function well. It:

- protects staff from pollutant and heat emissions within premises
- maintains a clean working atmosphere to protect product quality.

A ventilation plant is a system consisting of many interacting parts. For instance:

- the air system (intake, distributor, transport network)
- the fans (fans, motors, transmission systems)
- the ventilation control and regulation systems (flow variation, CTM, etc.)
- energy recovery devices
- air cleaners
- and the different types of ventilation system chosen (general ventilation, specific ventilation, with or without air-conditioning, etc.)

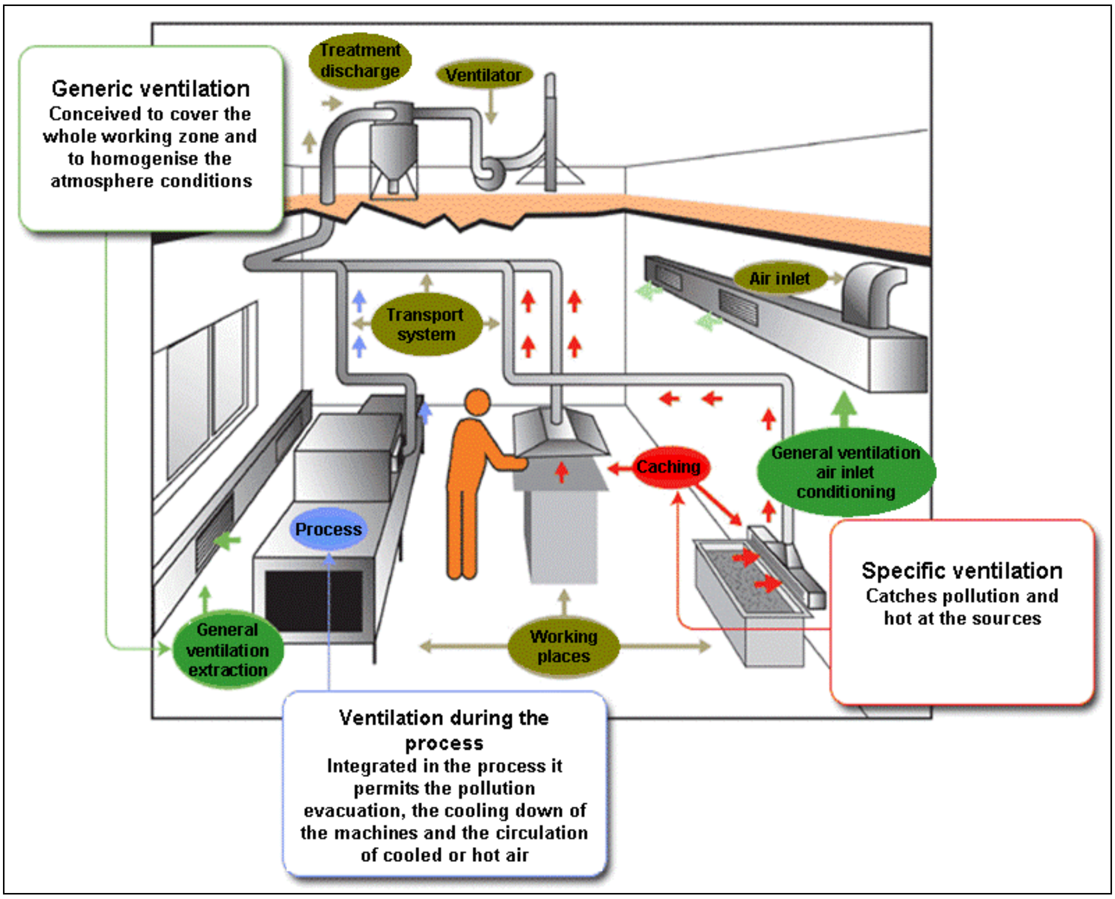

Figure 3.36: Ventilation system

*TWG: Is this diagram helpful? If so, we will arrange translation*

The following flow diagram can assist in determining the most suitable energy efficiency options for a particular situation:

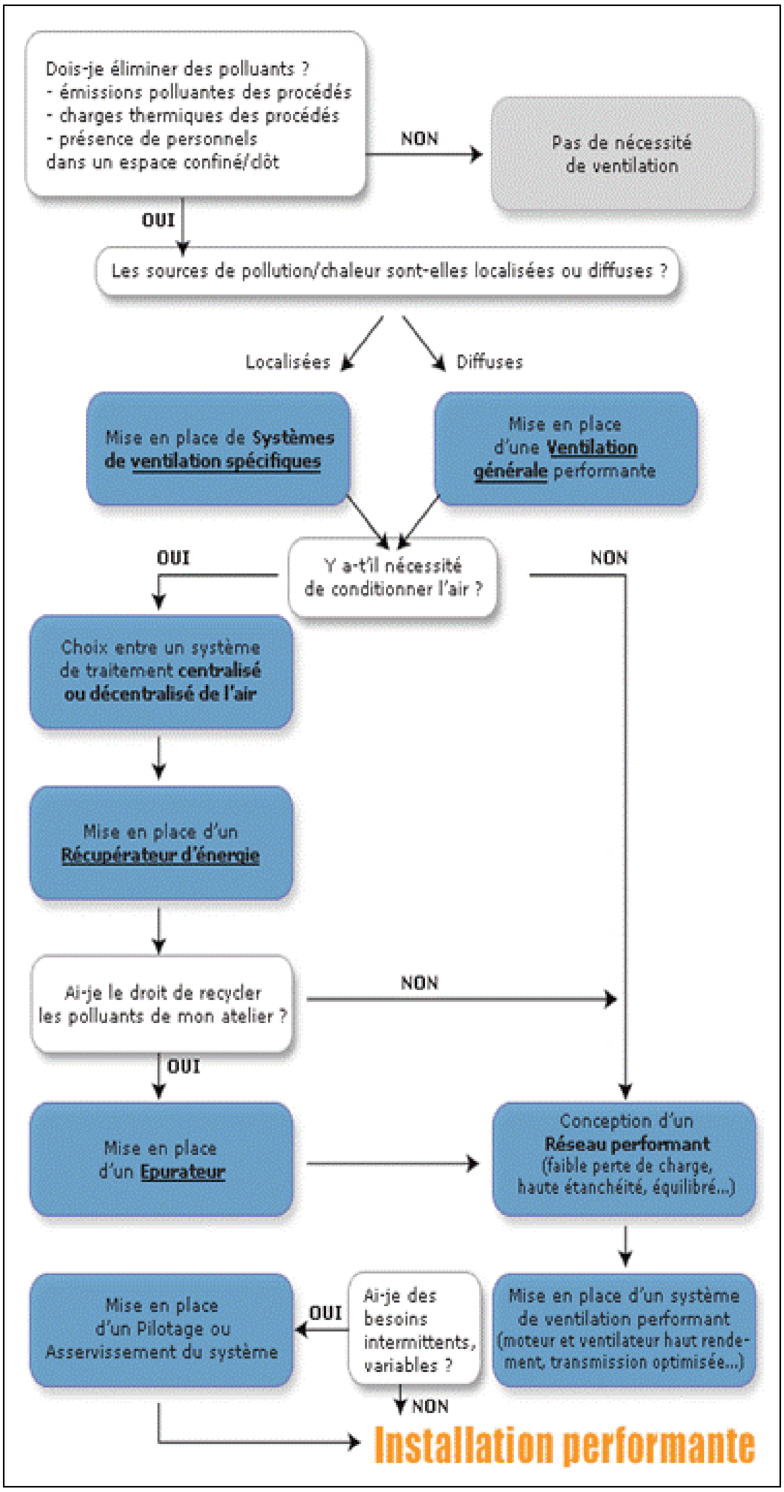

**Figure 3.37: Flow diagram to optimise energy use in ventilation systems**

*TWG: Is this diagram helpful? If so, we will arrange translation*

## 3.10.1 Design optimisation of a new or upgraded ventilation system

### Description

Having a clear idea of the requirements for a ventilation system helps to make the right choices and to decide on the right design. These may be:

- clean air intake
- maintenance of environmental conditions (temperature, pressure, humidity, etc.), for either improving comfort and health within working areas or product protection
- transportation of materials
- extraction of smoke, dust, humidity and hazardous products.

Interactions and their relative effects, particularly between the fan and the air duct system, can account for a high percentage of the losses in a given circuit. A coherent approach must therefore be used to design a system that meets both functional specifications and optimal energy efficiency requirements.

The following types of ventilation system can be used, see Figure 3.36:

- *General ventilation:* general ventilation systems are used to change the air in large volume working areas. Several types of clean air ventilation system are possible, depending on the premises to be ventilated, the pollution, and whether or not air-conditioning is required. Airflow is a major element influencing energy consumption.
  The lower the flowrate, the lower the energy consumption.

- *Specific ventilation:* specific ventilation systems are designed to remove emissions as close as possible to the source. Unlike general ventilation systems, they are directed at localised pollutant emissions. These systems have the advantage of capturing pollutants as soon as they are emitted, using specific intakes, and preventing them being propagated throughout the work area. They have the following advantages:
  - preventing any contact with its occupants
  - avoiding renewing all the air in the work area.

In both cases, extracted air may require treatment prior to discharge to the atmosphere (see the CWW BREF).

### Achieved environmetal benefits

It is estimated that 10 % of the electricity consumption in companies is by ventilation systems. Where there is also air-conditioning, ventilation and air conditioning can take up an even larger share of the corporate energy budget.

### Cross-media effects

None reported.

## Operational data

- *Fans*

Fans are the principal source of electricity consumption in the installation. Their type, size and controls are major factors from the point of view of energy. When designing or modifying an installation, key issues are:

- a fan with a high efficiency rating: the maximum efficiency of fans is generally between 60 and 85 % depending on the type of fan. Manufacturers are developing ranges of even more efficient fans
- a fan designed to operate as close as possible to its optimal rate: with a single fan, efficiency can vary according to its operating rate. It is therefore essential to choose the correct size of fan for the installation, so that it operates as close as possible to maximum efficiency.

Note that choosing a high efficiency fan of the correct size may mean that a smaller fan can be chosen and savings on the purchase price can be obtained.

- *The air system*

The design of an air system must meet certain conditions in order to be energy efficient:

- ducts must be sufficiently large in diameter (a 10 % increase in diameter can produce a 72 % reduction in the power absorbed)
- circular ducts, which offer less pressure loss, are better than rectangular ducts of an equal circumference
- avoid long runs and obstacles (bends, narrower sections, etc.)
- check that the system is airtight, particularly at joints
- check that the system is balanced at the design stage, to make sure all 'users' receive the necessary ventilation. Balancing the system after it has been installed means that single leaf dampers have to be installed in some ducts, increasing losses in pressure and energy.

- *Electric motors (and coupling with fans)*

Choose the correct type and size of motor (see electrical motor driven systems in Section 3.6).

- *Managing airflow*

Airflow is a basic parameter when it comes to energy consumption by ventilation systems. For example: for a 20 % reduction in flow, 50 % less power is consumed by the fan.
Most ventilation installations do not have to operate constantly at their maximum rate. So it is important to be able to adjust the fan operating speed in accordance with, e.g:

- production (quantity, product type, machine on/off, etc.)
- period (year, month, day, etc.)
- human occupation of the work area.

It is essential to analyse needs using presence detectors, a clock, and process-driven controls, and to design a controlled ventilation installation.

'Dual flow' ventilation, which combines blowing (the intake of fresh air) with extraction (the removal of polluted air), provides better airflow control and is more easily controlled, e.g. by the process air-conditioning and energy recovery management system. Installing automatic controls can provide a method of controlling the ventilation system using various (measured, defined, etc.) parameters and optimising its operation at all times (see Section 2.7.2).

There are many techniques for varying airflow in line with demand, but they are not all equally energy-efficient:

- electronic speed controls can be used to adapt the rate of operation of fans whilst optimising energy consumption by the motor, producing significant energy savings
- changing the blade angle of propeller fans also provides substantial energy savings.

- *Energy recovery system*

When ventilated premises have an air-conditioning system, the renewed air needs to be reconditioned, which consumes large amounts of energy. Energy recovery systems (exchangers) can be used to recover some of the energy contained in the polluted air expelled from the work area. When choosing an energy recovery system, check the following three parameters:

- thermal efficiency
- pressure loss
- behaviour when fouled.

- *Air filtering*

An air filter allows the air in the ventilated premises to be re-used. The flow of air to be renewed and reconditioned is thereby reduced, providing significant energy savings. Opting for an air filter when the ventilation installation is designed is advisable because the extra cost at that stage will be relatively small compared with installation at a later stage. It is essential to check that the pollutants that remain can be recycled. Where this solution is possible, it is important to know the following parameters:

- recycling efficiency
- pressure loss
- behaviour when filter is fouled.

To improve the operation of an existing installation; see Optimising existing systems.

### Applicability

Applicable to all new systems or when upgrading.

### Economics

In most audited installations, potential energy savings of up to 30 % of consumption have been detected. There are many possible actions giving a return on investment often within 3 years.

### Driving force for implementation

- health and safety conditions at work
- cost savings
- product quality.

### Examples

Widely used.

### Reference information

[202, IFTS, 1999]

### 3.10.2 Improving an existing ventilation system within an installation

**Description**
Note that improving ventilation system efficiency sometimes also brings improvements in:

- the comfort and safety of personnel
- product quality.

An existing ventilation system can be improved at three levels:

- optimisation of the operation of the installation
- introduction of a maintenance and monitoring plan for the installation
- investment in more efficient technical solutions.

**Achieved environmental benefits**
Energy saved after optimising all the parameters of the ventilation system will produce, on average, a reduction of the order of 30 % of the energy bill associated with its operation.

**Cross-media effects**
None reported.

**Operational data**
*Energy diagnosis (comprehensive audit)*
Knowing the installation is an essential precursor to improving its performance. A diagnosis of the installation enables the following:

- evaluation of the performance of the ventilation installation
- determination of the costs involved in producing compressed air
- detection of any malfunctions
- selection of a new installation of the correct size.

*Installation maintenance and monitoring*
The energy consumption of a ventilation installation increases over time for an identical service. To maintain its efficiency, it is necessary to monitor the system and when necessary carry out maintenance operations, which will produce substantial energy savings whilst increasing the lifetime of the installation. These operations may consist of:

- conducting leak detection and repair campaigns on the air duct system
- changing filters regularly, particularly in the air cleaning devices, because:
  - loss of pressure increases very rapidly with a worn-out filter
  - the filter's efficiency at removing particles deteriorates over time
- check compliance with health and safety standards associated with pollutant removal
- measure and record regularly the key values for the installation (electricity consumption and pressure loss in devices, airflow).

*Operation*

- *Immediate action:*
    - stop or reduce ventilation where possible. The energy consumption of a ventilation installation is directly linked to rate of airflow. Airflow is determined by:
        - the presence of operators
        - the number of sources of pollution and type of pollutants
        - the rate of pollution and distribution of each source of pollution
    - replace clogged filters
    - fix leaks in the air system
    - if the air is conditioned, check settings and ensure they suit current needs

- *Simple, effective action:*
    - equip workstations with appropriate specific intakes
    - optimise the number, shape and size of the pollutant intakes to reduce as much as possible the airflow necessary for removing pollutants (see the STM BREF)
    - consider regulating ventilation flow automatically according to actual need. There are many possible ways of controlling this regulation:
        - having ventilation automatically controlled by a machine when it stops and starts (most of the time this function is provided by machine tools or welding torches fitted with a vacuum)
        - having ventilation automatically triggered by the emission of pollution. For example, putting a part into a treatment bath changes the rate of emission of pollution. Ventilation can, in this case, be accelerated when parts are immersed and reduced the rest of the time
        - closing baths or tanks when not in use, manually or automatically (seethe STM BREF)

    Note that where flow is regulated, it will be necessary to check that the health conditions are still correct in all conditions of operation.

    - Air duct systems must be balanced to prevent over-ventilation at certain points. Balancing can be carried out by a specialist company.

- *Cost-effective action:*
    - fit fans where there is variable flow with electronic speed control (ESC)
    - install high efficiency fans
    - install fans with an optimum operating rate that suits your installation and needs
    - install high efficiency motors (e.g. EFF1 labelled)
    - integrate the management of the ventilation system into a centralised technical management system (CTM)
    - introduce measurement instrumentation (flow-meters, electricity meters) to monitor the operation of the installation
    - investigate the possibility of integrating air filters into the air duct system and energy recovery devices to avoid large energy losses when expelling polluted air
    - investigate the possibility of modifying the whole ventilation system and breaking it down into general ventilation, specific ventilation and process ventilation

### Applicability
Applicable to all existing systems.

### Economics
In most audited installations, potential energy savings of up to 30 % of consumption have been detected. There are many possible actions giving a return on investment often within two years.

### Driving force for implementation
- health and safety conditions at work
- cost savings
- product quality

### Examples
Widely used.

### Reference information
[202, IFTS, 1999]

## 3.11 Lighting

Artificial lighting consumes a significant part of all electrical energy consumed worldwide. In homes and offices from 20 to 50 per cent of total energy consumed is due to lighting. Most importantly, for some buildings over 90 per cent of lighting energy consumed can be an unnecessary expense through over-illumination. Thus lighting represents a critical component of energy use today, especially in large office buildings and other large scale uses where there are many alternatives for energy utilisation in lighting [Hawken, 2000].

Lighting types are classified by intended use as general, localised, or task lighting, depending largely on the distribution of the light produced by the fixture.

General lighting is intended for general illumination of an area. Indoors, this would be a basic lamp on a table or floor, or a fixture on the ceiling. Outdoors, general lighting for a parking area may be as low as 10 – 20 lux (1 – 2 footcandles) since pedestrians and motorists already used to the dark will need little light for crossing the area.

Task lighting is mainly functional and is usually the most concentrated, for purposes such as reading or inspection of materials. For example, reading poor quality print products may require task lighting levels up to 1500 lux (150 footcandles), and some inspection tasks or surgical procedures require even higher levels.

### 3.11.1 Techniques to reduce energy losses in lighting systems

**Description**
There are several strategies available to minimise energy requirements in any building:

- specification of illumination requirements for each given use area. This is the basic concept of deciding how much illumination is required for a given task. Clearly, much less light is required to illuminate a walkway compared to that needed for a computer work station. Generally speaking, the energy expended is proportional to the design illumination level. For example, a lighting level of 80 footcandles might be chosen for a work environment involving meeting rooms and conferences, whereas a level of 40 footcandles could be selected for building hallways
- analysis of lighting quality to ensure that adverse components of lighting (for example, glare or incorrect colour spectra) are not biasing the design. Analysis of lighting quality particularly emphasises use of natural lighting, but also considers spectral content if artificial light is to be used. Not only will greater reliance on natural light reduce energy consumption, but will favourably impact human health and performance
- integration of space planning and interior architecture (including choice of interior surfaces and room geometries) to lighting design
- design of time of day use that does not expend unnecessary energy
- selection of fixture and lamp types that reflect best available technology for energy conservation
- training of building occupants to utilize lighting equipment in most efficient manner
- maintenance of lighting systems to minimize energy wastage.

Data on options, such as types of lighting, is available via the Green Light Programme. This is a voluntary prevention initiative encouraging non-residential electricity consumers (public and private), referred to as 'Partners', to commit towards the European Commission to install energy-efficient lighting technologies in their facilities when (1) it is profitable, and (2) lighting quality is maintained or improved.

### Achieved environmental benefits

Energy savings.

### Cross-media effects

None reported.

### Operational Data

It is valuable to provide the correct light intensity and colour spectrum for each task or environment. Otherwise, energy not only could be wasted but over-illumination could lead to adverse health and psychological effects such as headache frequency, stress, and increased blood pressure may be induced by the higher lighting levels. In addition, glare or excess light can decrease worker efficiency [DiLouie, 2006]. Artificial nightlighting has been associated with irregular menstrual cycles.

The determination of energy savings is a challenge, and requires both accurate measurement and repeatable methodology, known as a measurement and verification protocol. The Protocol described here is called the 'International Performance Measurement and Verification Protocol' (IPMVP).

The IPMVP is a protocol which discusses procedures that, when implemented, allow building owners, energy service companies (ESCOs), and financiers of buildings energy efficiency projects to quantify energy conservation measure (ECM) performance and energy savings[17]. Energy savings are determined by comparing energy use associated with a facility, or certain systems within a facility, before and after the energy conservation measure (ECM). The 'before' case is called the baseline model. The 'after' case is called the post-installation model. Baseline and post-installation models can be constructed using the methods associated with M&V options A, B, C and D described hereafter in Table 3.25.

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[17] The IPMVP provides an overview of current best practice techniques available for verifying savings from both traditionally- and third-party-financed projects. It has been developed by a worldwide network of corresponding members to incorporate international expertise and to develop consensus among professionals from around the world.

| M&V Option | How savings are calculated | Cost |
|---|---|---|
| Option A: Focuses on physical assessment of equipment changes to ensure the installation is to specification. Key performance factors (e.g. lighting wattage) are determined with spot or short-term measurements and operational factors (e.g. lighting operating hours) are stipulated based on analysis of historical data or spot/short-term measurements. Performance factors and proper operation are measured or checked yearly | Engineering calculations using spot or short-term measurements, computer simulations, and/or historical data | Dependent on number of measurement points. Approx. 1–5 % of project construction cost |
| Option B: Savings are determined after project completion by short-term or continuous measurements taken throughout the term of the contract at the device or system level. Both performance and operations factors are monitored | Engineering calculations using metered data | Dependent on number and type of systems measured and the term of analysis/metering. Typically 3 – 10 % of project construction cost |
| Option C: After project completion, savings are determined at the 'whole building' or facility level using the current year and historical utility meter or sub-meter data | Analysis of utility meter (or sub-meter) data using techniques from simple comparison to multivariate (hourly or monthly) regression analysis | Dependent on number and complexity of parameters in analysis. Typically 1 – 10 % of project construction cost |
| Option D: Savings are determined through simulation of facility components and/or the whole facility | Calibrated energy simulation/modeling; calibrated with hourly or monthly utility billing data and/or end-use metering | Dependent on no. and complexity of systems evaluated. Typically 3 – 10 % of project construction cost |

**Table 3.25: Savings in lighting systems**

The only section of the protocol which is relevant to lighting is reproduced here. For more information, the entire protocol can be downloaded at http://www.ipmvp.org/

**Applicability**
All IPPC installations.

**Economics**
The Green Light investments use proven technology, products and services which can reduce lighting energy use from 30 to 50 %, earning rates of return of between 20 and 50 %.

Payback can be calculated using techniques in the ECM BREF.

**Driving force for implementation**

- Health and safety at work
- Energy savings.

**Examples**
Widely used.

**Reference information**
[209, Wikipedia, , 210, EC, 2000]

*Additionnal references:*
[211, ADEME, 1997, 212, BRE_UK, 1995, 213, EC, , 214, EC, 1996, 215, Initiatives, 1993, 216, Initiatives, 1995, 217, Piemonte, 2001, 218, Association, 1997, 219, IDAE]

# 4 BEST AVAILABLE TECHNIQUES

## 4.1 Introduction

In understanding this chapter and its contents, the attention of the reader is drawn back to the preface of this document and in particular the sixth section of the preface: 'How to understand and use this document'. The techniques and associated energy efficiencies presented in this chapter have been assessed through an iterative process involving the following steps:

- identification of the key energy efficiency issues within the scope of the IPPC directive (see the Preface and Scope)[18]
- examination of the techniques most relevant to address these key issues
- identification of the best energy efficiencies achievable, on the basis of the available data in the European Union and worldwide
- examination of the conditions under which these performance levels were achieved; such as costs, cross-media effects, and the main driving forces involved in implementation of the techniques
- selection of the best available techniques (BAT) in a general sense according to Article 2(11) and Annex IV to the Directive.

Expert judgement by the European IPPC Bureau and the relevant Technical Working Group (TWG) has played a key role in each of these steps and in the way in which the information is presented here.

On the basis of this assessment, techniques, and as far as possible energy efficiencies associated with the use of BAT, are presented in this chapter that are considered to be appropriate generally and in many cases reflect the current performance of some installations within a sector. Where energy efficiencies 'associated with best available techniques' are presented, this is to be understood as meaning that those levels represent the performance that could be anticipated as a result of the application of the techniques described, bearing in mind the balance of costs and advantages inherent within the definition of BAT. However, they are not energy efficiency limit values and should not be understood as such. In some cases it may be technically possible to achieve better efficiencies but due to the costs involved or cross-media considerations, they are not considered to be appropriate as BAT generally. However, such levels may be considered to be justified in more specific cases where there are special driving forces.

The energy efficiencies associated with the use of BAT have to be seen together with any specified reference conditions (e.g. an EU average for the industry, system or situation the technique is applied in).

Where available, data concerning costs have been given together with the description of the techniques presented in the previous chapters. These give a rough indication about the magnitude of the costs involved. However, the actual cost of applying a technique will depend strongly on the specific situation regarding, for example, taxes, fees, and the technical characteristics of the installation concerned. It is not possible to evaluate such site-specific factors fully in this document. In the absence of data concerning costs, conclusions on economic viability of techniques are drawn from observations on existing installations.

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[18] The scope of this document and the IPPC Directive, and the interface with other legislation and policy commitments is discussed in the Preface and Scope. This document therefore does not discuss such issues as the use of renewable energy sources.

It is intended that the general BAT in this chapter are a reference point against which to judge the current performance of an existing installation or to judge a proposal for a new installation. In this way they will assist in the determination of appropriate 'BAT-based' conditions for the installation or in the establishment of general binding rules under Article 9(8) of the IPPC Directive. It is foreseen that new installations can be designed to perform at or even better than the general BAT levels presented here. It is also considered that existing installations could move towards the general BAT levels or do better, subject to the technical and economic applicability of the techniques in each case.

While the BAT reference documents do not set legally binding standards, they are meant to give information for the guidance of industry, Member States and the public on achievable emission and consumption levels (including energy efficiencies) when using specified techniques. The appropriate conditions for any specific case will need to be determined taking into account the objectives of the IPPC Directive and the local considerations.

Identification of horizontal BAT

The horizontal approach to energy efficiency in all IPPC sectors is based on the premise that energy is used in all installations, and that common systems and equipment occur in many IPPC sectors. Generic options for energy efficiency can therefore be identified independently of a specific activity. On this basis, BAT can be derived that embrace the most effective measures to achieve a high level of energy efficiency as a whole. Because this is a horizontal BREF, BAT needs to be determined more broadly than for a vertical BREF, such as to consider the interaction of processes, units and systems within a site.

It is also important to bear in mind the importance of energy efficiency (as discussed in the Scope and Chapter 1). However, *'even the single objective of ensuring a high level of protection for the environment as a whole will often involve making trade-off judgements between different types of environmental impact, and these judgements will often be influenced by local considerations'* (see the Preface).

Process-specific BAT for energy efficiency and associated energy consumption levels are given in the appropriate BREFs. As the first edition of all the BREFs has been completed, these have been broadly summarised in Annex 13.

BAT for specific installations is therefore the combination of the generic BAT elements presented in this chapter and the specific BAT elements in the relevant sector BREFs.

Implementation of BAT

The implementation of BAT in new or significantly upgraded plants or processes is not usually a problem. In most cases, it makes economic sense to optimise energy efficiency. Within an existing installation, the implementation of BAT is not generally so easy, because of the existing infrastructure and local circumstances: the economic and technical viability of upgrading these installations needs to be taken into account (see the Preface).

Nevertheless, this document does not generally distinguish between new and existing installations. Such as distinction would not encourage the operators of industrial sites to move towards adopting BAT. There is generally a payback associated with energy efficiency measures and due to the high importance attached to energy efficiency, many policy implementation measures, including financial incentives, are available. Some of these are discussed in Chapter 5.

Some techniques are very desirable, and often implemented, but may require the availability and co-operation of a third party (e.g. cogeneration), which is not considered in the IPPC Directive. Such techniques are defined as good practice.

## 4.2 Best available techniques for achieving energy efficiency at an installation level

*The original standard EMS text is in black*
*Green shows the standard EMS text used in Ch 2 E2MS section*
*Blue is new text modified for E2*

The key element to deliver energy efficiency at an installation level is a formal management approach, described in BAT 1. This is supported by the BAT and Good Practice in the following sections.

### 4.2.1 Energy efficiency management

A number of energy efficiency management techniques are determined as BAT. The scope (e.g. level of detail) and nature of the E2MS (e.g. standardised or non-standardised) will generally be related to the nature, scale and complexity of the installation, as well as the energy requirements of the component processes and systems (see Section 2.1):

1. **BAT is to implement and adhere to an energy efficiency management system (E2MS) that incorporates, as appropriate to the local circumstances, the following features (see Section 2.1.** The letters (a), (b), etc. below, correspond those in Section 2.1**):**

(a) commitment of top management (commitment of the top management is regarded as a precondition for the successful application of energy efficiency management)

(b) definition of an energy efficiency policy for the installation by top management

(c) planning and establishing objectives and targets (see BAT 2, 3 and 6)

(d) implementation and operation of procedures paying particular attention to:
  1) structure and responsibility
  2) training, awareness and competence
  3) communication
  4) employee involvement
  5) documentation
  6) efficient process control
  7) maintenance programmes (see BAT 14)
  8) emergency preparedness and response
  9) safeguarding compliance with energy efficiency- related legislation and agreements

(e) benchmarking: the application of internal benchmarks and systematic and regular comparisons with sector, national or regional benchmarks for energy efficiency, as applicable (see Sections 2.1(e), 2.10 and BAT 7)

(f) checking performance and taking corrective action paying particular attention to:
  1) monitoring and measurement (see BAT 15)
  2) corrective and preventive action
  3) maintenance of records
  4) independent (where practicable) internal auditing in order to determine whether or not the energy efficiency management system conforms to planned arrangements and has been properly implemented and maintained (see BAT 4 and 5)

(g) review of the E2MS and its continuing suitability, adequacy and effectiveness by top management

(j) when designing a new unit, taking into account the environmental impact from the eventual decommissioning of the unit

(k) development of energy efficient technologies, and to following developments

The E2MS may be achieved by ensuring these elements form part of existing management systems (such as an EMS) or implementing a separate energy efficiency management system.

Three further features are considered as supporting measures. However, their absence is generally not inconsistent with BAT. These three additional steps are:

- (see Section 2.1(h)) preparation and publication (and possibly external validation) of a regular energy efficiency statement describing all the significant environmental aspects of the installation, allowing for year-by-year comparison against environmental objectives and targets as well as with sector benchmarks as appropriate

- (see Section 2.1(i)) having the management system and audit procedure examined and validated by an accredited certification body or an external E2MS verifier

- (see Section 2.1, Applicability, 2) implementation and adherence to a nationally or internationally accepted voluntary system such as:

    - DS2403, IS 393, SS627750, VDI Richtlinie No. 46, etc
    - or (when including energy efficiency management in an EMS) EMAS and EN ISO 14001:1996.

  This voluntary step could give higher credibility to the E2MS. In particular EMAS, which embodies all the above-mentioned features, gives higher credibility. However, non-standardised systems can in principle be equally effective provided that they are properly designed and implemented.

*Applicability: All installations. The scope (e.g. level of detail) and nature of applying this E2MS will depend on the nature, scale and complexity of the installation, and the energy requirements of the component processes and systems.*

## 4.2.2 Planning and establishing of objectives and targets

### 4.2.2.1 Continuous environmental improvement

An important aspect of environmental management systems is continuing environmental improvement. This requires maintaining a balance for an installation between consumption of energy, raw materials and water, and the emissions (see Sections 1.1.4 and 2.2.1). Planned continuous improvement can also achieve the best cost-benefit for achieving energy saving (and other environmental benefits).

2. **BAT is to minimise the environmental footprint of an installation by planning actions and investments on an integrated basis and for the short, medium and long-term, considering the cost-benefits and cross-media effects.**

*Applicability: All installations.*

#### 4.2.2.2 Identification of energy efficiency aspects of an installation and opportunities for energy saving

In order to optimise energy efficiency, the aspects of an installation that influence energy efficiency need to be identified and quantified (see Section 2.6). Energy savings can then identified, evaluated, prioritised and implemented according to BAT 2, above (see Section 2.1(c)).

3. **BAT is to identify the aspects of an installation that influence energy efficiency by carrying out an audit. It is important that an audit is coherent with a systems approach (see BAT 7).**

*Applicability: All installations. The scope of the audit and nature (e.g. level of detail) will depend on the nature, scale and complexity of the installation and the energy consumption of the component processes and systems (see Section 2.6) e.g.:*

- *in large installations with many systems and individual energy-using components such as motors, it will be necessary to prioritise data collection to necessary information and significant uses*
- *in smaller installation, a walk-through type audit may be sufficient.*

4. **BAT is to ensure that an audit identifies the following aspects (see Section 2.8):**

   **a)** energy use and type in the installation and its component systems and processes

   **b)** energy-using equipment, type and quantity of energy used in the installation

   **c)** possibilities to minimise energy use, such as:
   - controlling/reducing operating times, e.g. switching off when not in use (e.g. see Sections 3.6, 3.7, 3.8, 3.9, 3.10, and 3.11)
   - ensuring insulation is optimised, see Sections 3.2.8 and 3.2.8.1
   - optimising utilities, see Chapter 3

   **d)** possibilities to use alternative sources or use of energy that is more efficient, in particular energy surplus to other processes and/or systems, see Section 3.3.

   **e)** possibilities to apply energy surplus to other processes and/or systems, see Section 3.3.

   **f)** possibilities to upgrade heat quality (see Section 3.3.2)

*Applicability: All installations. The scope of the audit and nature (e.g. level of detail) will depend on the nature, scale and complexity of the installation, and the energy consumption of the component processes and systems.*

*Details for optimising systems and processes are given in the relevant sections in Chapter 3.*

5. **BAT is to use appropriate tools or methodologies to assist with identifying and quantifying energy optimisation, such as:**

   - energy models, databases and balances (see Section 2.7.4)
   - pinch technology (see Section 2.9)
   - exergy and enthalpy analysis (see Section 2.10)
   - Sankey diagrams (see Section 2.11)
   - EMAT (see Section 2.13)

*Applicability: The appropriate tool or tools will be site-specific, and are discussed in the relevant sections.*

6. **BAT is to identify opportunities to optimise energy recovery within the installation, between systems within the installation (see BAT 7) and/or with a third party (or parties).**

*Applicability: The scope for energy recovery depends on there being a suitable use for the heat at the type and quantity recovered (see Sections 3.3 and 3.4 , and Chapter 5). A systems approach is set out in Section 2.2.2 and BAT 7)*

*The co-operation and agreement of a third party is not within the control of the operator, and therefore may not be within the scope of an IPPC permit*

#### 4.2.2.3 Systems approach to energy management

The major energy efficiency gains are achieved by viewing the installation as a whole and assessing the needs and uses of the various systems, their associated energies and their interactions (see Sections 1.3.4, 1.4.2 and 2.2.2).

7. **BAT is to optimise energy efficiency by taking a top down, systems approach to energy management in the installation. Systems to be considered for optimising as a whole are, for example:**

- process units (see sector BREFs)
- heating systems such as
  - steam (see Section 3.2)
  - hot water
- cooling and vacuum (see CV BREF)
- motor driven systems such as
  - compressed air (see Section 3.7)
  - pumping(see Section 3.8)
- drying (see Section 3.9)
- lighting (see Section 3.11)

*Applicability: All installations. The scope (e.g. level of detail) and nature of applying this technique will depend on the nature, scale and complexity of the installation, and the energy requirements of the component processes and systems.*

#### 4.2.2.4 Establishing and reviewing energy efficiency objectives and indicators

Quantifiable, recorded energy efficiency objectives are crucial for achieving and maintaining energy efficiency. Areas for improvement are identified from an audit (see BAT 5). Indicators need to be established to assess the effectiveness of energy efficiency measures. For process industries, these are preferably indicators related to production throughput (e.g. GJ/t product, see Section 1.3). Where a single energy objective (such as SEC) cannot be set, or where it is helpful, the efficiency of individual processes, units or systems may be assessed. Indicators for processes are often given in the relevant sector BREFS (for an overview, see Annex 13 or 14).

Production parameters (such as production rate, product type) vary and these may affect the measured energy efficiency and should be recorded to explain variations and to ensure that energy efficiency is realised by the techniques applied (see Sections 1.4 and 1.5). Energy use and transfers may be complicated and the boundary of the installation or system being assessed should be carefully defined on the basis of entire systems (see Sections 1.3.4 and 1.4.2 and BAT 2). Energy should be calculated on the basis of primary energy, or the energy uses shown as secondary energy for the different utilities (e.g. process heat as steam use in GJ/t, see Section 1.3.5.1).

**8. BAT is to establish energy efficiency indicators by carrying out all of the following:**

a) identifying suitable efficiency energy indicators for the installation, and where necessary, individual processes, systems and/or units, and measure their change over time or after the implementation of energy efficiency measures (see Sections 1.3 and 1.3.3)

b) identifying and record appropriate boundaries associated with the indicators (see Sections 1.3.4 and 1.5.1)

c) identifying and record factors that can cause variation in the energy efficiency of the relevant process, systems and/or units (see Sections 1.3.5 and 1.5.2)

d) calculating energy efficiency based on primary energies, or as secondary energy for the relevant utilities (see Section 1.3.5.1)

*Applicability: All installations. The scope (e.g. level of detail) and nature of applying this technique will depend on the nature, scale and complexity of the installation, and the energy consumption of the component processes and systems*.

#### 4.2.2.5 Benchmarking

Benchmarking is a powerful tool for assessing the performance of a plant and the effectiveness of energy efficiency measures, as well as overcoming paradigm blindness[19]. Data may be found in sector BREFs, trade association data, national guidance documents, theoretical energy calculations for processes, etc. Data should be comparable and may need to be corrected, e.g. for type of feedstock. Data confidentiality may be important, such as where energy consumption is a significant part of the cost of production, although it may be possible to protect data. (see Section 2.10). See also the establishment of energy indicators in BAT 6.

Benchmarking can also be applied to processes and working methods (see Section 2.2.5)

**9. BAT is to carry out systematic and regular comparisons with sector, national or regional benchmarks.**

*Applicability: All installations. The level of detail will depend on the nature, scale and complexity of the installation, and the energy consumption of the component processes and systems. Confidentiality issues may need to be addressed (see Section 2.10): for instance, the results of benchmarking may remain confidential.*

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[19] Paradigm blindness is a term used to describe the phenomena that occurs when the dominant paradigm prevents one from seeing viable alternatives, i.e. 'the way we do it is best, because we've always done it this way'

### 4.2.2.6 Energy efficient design (EED)

The planning phase of a new installation, unit or system (or one undergoing major refurbishment) offers the opportunity to consider the life-time energy costs of processes, equipment and utility systems, and to select the most energy efficient options, with best lifetime costs (see Section 2.1(c)).

10. **BAT is to optimise energy efficiency when planning a new installation, unit or system or a significant upgrade as follows (see Section 2.2.2)is to consider all of the following:**

    **a)** the EED should be initiated at the early stages of the conceptual design/basic design phase, even though the planned investments may not be not well-defined

    **b)** additional data collection may need to be carried out as part of the design project or separately to supplement existing data or fill gaps in knowledge

    **c)** the EED work should be carried out by an energy expert independent from the design organisation (or team)

    **d)** the independent energy expert should be technically capable, with significant experience in working with complex organisations and with complex technical problems.

    **e)** the initial mapping of energy consumption should also address which parties in the project organisations influence the future energy consumption, and optimise the energy efficiency design of the future plant with them. For example, the staff in the (existing) installation who may be responsible for specifying design parameters.

    **f)** a risk assessment of tenders and other data should clarify which manufactures will not benefit from optimising energy efficiency of their delivered products for the project. For example, strong price competition may result in manufactures minimising heat recovery equipment.

*Applicability: All new and significantly refurbished installation, major processes and systems.*

### 4.2.2.7 Selection of process technology

The planning and design of new or upgraded plant, system or installation enables the development and/or selection of energy efficient technologies (see Sections 2.1(k)) and 2.2.3.1)

11. **BAT is to develop and/or select energy efficient technologies when planning and designing a new or upgraded installation, process or system.**

*Applicability: New and significantly refurbished installations, processes and systems*

### 4.2.2.8 Increased process integration

There are additional benefits to seeking process integration, such as optimising raw material usage.

**12. BAT is to seek to optimise the energy use between more than one process or system (see Section 2.2.4), within the installation or with third party.**

*Applicability: All installations. The scope (e.g. level of detail) and nature of applying this technique will depend on the nature, scale and complexity of the installation, and the energy requirements of the component processes and systems*.

*The co-operation and agreement of a third party is not within the control of the operator, and therefore may not be within the scope of an IPPC permit*

### 4.2.2.9 Maintaining the impetus of energy efficiency initiatives

To successfully achieve ongoing energy efficiency improvement over time, it is necessary to maintain the impetus of energy efficiency programmes (see Section 2.2.5).

**13. BAT is to maintain the impetus of the energy efficiency programme by using a variety of techniques, such as:**

a) implementing a specific energy efficiency management system (see Section 2.1 and BAT 1)

b) accounting for energy usage based on real (metered) values, which places both the obligation and credit for energy efficiency on the user/bill payer (see Sections 2.2.5, 2.7.2 and 2.7.5)

c) a fresh look at existing management systems, such as using Operational Excellence (see Section 2.2.5)

d) using change management techniques (also a feature of Operational Excellence, see Section 2.2.5)

e) benchmarking (see Section 2.10 and BAT 7)

*Applicability: All installations. The scope (e.g. level of detail) and nature of applying this technique will depend on the nature, scale and complexity of the installation, and the energy consumption of the component processes and systems*.

### 4.2.3 Maintaining expertise

Human resources are required for the implementation and control of energy efficiency management, and all staff whose work may affect energy should receive training (see Section 2.1(d)(i) and (ii), and Section 2.3).

**14. BAT is to maintain expertise in energy efficiency and energy-using systems by one or more of the following:**

a) recruitment of skilled staff and/or training of staff. Training can be delivered by in-house staff, by external experts or by formal courses (see Section 2.3)

b) taking staff off-line periodically to perform fixed term/specific investigations (in their original installation or in others, see Section 2.2.5)

c) sharing in-house resources between sites (see Section 2.2.5)

d) use of appropriately skilled consultants for fixed term investigations (e.g. see Section 2.8)

e) outsourcing specialist systems and/or functions (e.g. see Section 5.1.10)

*Applicability: All installations. The scope (e.g. level of detail) and nature of applying this technique will depend on the nature, scale and complexity of the installation, and the energy requirements of the component processes and systems*.

### 4.2.4 Effective process control

**15. BAT is to ensure that effective process control is implemented by:**

a) having systems in place to ensure that procedures are known, understood and complied with (see Sections 2.1(d)(vi) and 2.2.5)

b) ensuring that the key performance parameters are identified, optimised for energy efficiency and monitored (see Section 2.5)

c) documenting these parameters (see Sections 2.1(d)(vi) and 2.2.5).

*Applicability: All installations. The scope (e.g. level of detail) and nature of applying this technique will depend on the nature, scale and complexity of the installation, and the energy requirements of the component processes and systems*.

### 4.2.5 Maintenance

Structured maintenance and the prompt repair of energy-using and controlling equipment is essential for achieving and maintaining efficiency (see Sections 2.1(d)(vii), 2.6 and BAT 1).

16. **BAT is to carry out maintenance at installations to optimise energy efficiency by applying all of the following:**

    a) clearly allocating responsibility for the planning and execution of maintenance

    b) establishing a structured programme for maintenance based on technical descriptions of the equipment, norms etc. as well as any equipment failures and consequences

    c) supporting the maintenance programme by appropriate record keeping systems and diagnostic testing

    d) identifying from routine maintenance, breakdowns and/or abnormalities possible losses in energy efficiency, or where energy efficiency could be improved

    e) promptly identifying and rectifying leaks, broken equipment, worn bearings, etc. that affect or control energy usage.

*Applicability: All installations. The scope (e.g. level of detail) and nature of applying this technique will depend on the nature, scale and complexity of the installation, and the energy requirements of the component processes and systems*.

### 4.2.6 Monitoring and measurement

Monitoring and measurement are an essential part of checking in a ‘plan-do-check-act’ system, such as in energy management (Section 2.1). It is also a part of effective process control (see BAT 13).

17. **BAT is to establish and maintain documented procedures to monitor and measure, on a regular basis, the key characteristics of operations and activities that can have a significant impact on energy efficiency. Some suitable techniques are given in Section 2.7.**

*Applicability: All installations. The scope (e.g. level of detail) and nature of applying this technique will depend on the nature, scale and complexity of the installation, and the energy requirements of the component processes and systems*.

## 4.3 Best available techniques for achieving energy efficiency in energy using systems, processes or activities

### 4.3.1 Combustion

Combustion is a widely used process for both direct heating (such as in cement and lime manufacture, steel making) and indirect heating (such as power generation and firing steam boiler systems). Techniques for energy efficiency in combustion are therefore addressed in the appropriate sector BREFs. The Scope of the LCP BREF states:

> *'...smaller units can potentially be added to a plant to build one larger installation exceeding 50 MW. This means that all kinds of conventional power plants (e.g. utility boiler, combined heat and power plants, district heating plants, etc.) used for mechanical power and heat generation are covered by this [LCP BREF] work.'*

The LCP BREF covers:

- various fuel types: coal and lignite, biomass and peat, liquid fuels, gaseous fuels and co-combustion and related upstream and downstream techniques, such as fuel drying
- common combustion processes.

The WT BREF covers the pretreatment of secondary fuels.

The reader's attention is therefore directed to the techniques and conclusions in the LCP, WT and the relevant sector BREFs. In addition, Section 3.1

**18. BAT is to optimise the energy efficiency of combustion by one or a combination of the relevant techniques:**

a) in the LCP BREF

b) techniques in Table 4.1.

| Technique | Applicability | Cross- reference |
|---|---|---|
| Development of an improvement strategy by analysing and benchmarking the system performance, and improving the system operation and management | All | 2.2.2, 2.2.3, 2.6, 3.1 |
| Design for e.g. replacing combustion system | New systems and significant rebuilds | 2.2.3 |
| Improving operating procedures and boiler controls | All | 2.5.5 model-utilities |
| Maintenance | All | 2.4 |
| Reducing the mass flow of the flue-gases by reducing the excess air | Depends on burner, process and ELVs | 3.1.2 |
| Reducing the mass flow of the flue-gases by firing with oxygen | The primary energy used to concentrate oxygen should be considered. The technique is primarily a $NO_X$ reduction technique. | 3.1.3 |
| Reducing heat losses by insulation | Low cost if carried out at shut down. Hot repairs can be carried out. | 3.1.4 |
| Losses through furnace doors | | 3.1.5 |
| Drying the fuel before use (e.g. biomass) | | See LCP BREF |

**Table 4.1: Combustion: techniques to improve energy efficiency**

## 4.3.2 Steam systems

Steam is a widely used heat transport media because of its non-toxic nature, stability, low cost and high heat capacity, and flexibility in use. Steam utilisation efficiency is frequently neglected, as it is as easily measured as the thermal efficiency of a boiler. It may be determined using tools such as pinch technology and exergy analysis (see Sections 2.9 and 2.10) in conjunction with appropriate monitoring (see Section 2.7), where appropriate.

**19. BAT for steam systems is to optimise the energy efficiency by using the techniques in Table 4.4 according to applicability:**

| Technique | Applicability | Cross - reference |
|---|---|---|
| **DESIGN and CONTROL** | | |
| Development of an improvement strategy by analysing and benchmarking the system performance, and improving the system operation and management | All | 2.2.2, 2.2.3, 2.6, 3.2 |
| Design for e.g. replacing boiler(s) | New systems and significant rebuilds | 2.2.3 |
| Energy efficient design and installation of steam distribution pipework. | New systems and significant rebuilds | 3.2.15 |
| Improving operating procedures and boiler controls | All | 3.2.3 |
| Using sequential boiler controls | Applicable only to sites with more than one boiler | |
| Installing flue-gas isolation dampers | Applicable only to sites with more than one boiler | |
| **GENERATION** | | |
| Minimise excess air | Widely applicable | 3.1 |
| Clean boiler heat transfer surfaces<br>Prevention and removal of scale deposits on heat transfer surfaces | Widely applicable | 3.1<br>3.1.1 |
| Install heat recovery equipment (feed-water economisers and/or combustion air preheaters) | Standard on high output plants. Others on a site basis. | 3.1.1.1, 3.2.4 |
| Improve water treatment to minimise boiler blowdown<br>Installing automatic total dissolved solids control | Widely applicable | 3.2.6 |
| Recover energy from boiler blowdown | Widely applicable | 3.2.7 |
| Add/restore boiler refractory | Where poor insulation identified | |
| Optimise deaerator vent rate | All | 3.2.14 |
| Minimise boiler short cycling losses | All | 3.2.13 |
| Carrying out boiler maintenance | All | 2.4 |
| **DISTRIBUTION** | | |
| Planned maintenance programme to cover the issues in this table | All | 2.4 |
| Repair steam leaks | All | 3.2.15 |
| Minimised venting in the system | All | 3.2.10 |
| Ensure that steam system piping, valves, fittings and vessels are well insulated | All | 3.2.8 , 3.2.9 |
| Implement an effective steam-trap maintenance program | All | 3.2.10 |
| Isolate steam from unused lines | All | 3.2.15 |
| Utilise backpressure turbines instead of PRVs | *TWG to advise* | Annex 1 |
| **RECOVERY** | | |
| Optimise condensate recovery | All | 3.2.11 |
| Use high-pressure condensate to make low-pressure steam (flash steam) | *TWG to advise* | 3.2.12 |

**Table 4.2: Steam: techniques to improve energy efficiency**

### 4.3.3 Waste heat recovery

The main types of heat recovery systems are (described in Section 3.3):

- heat exchangers
- heat pumps.

Heat recovery systems are widely used with good results in many industrial sectors and systems, and are widely used for implementing BAT 2, 3 and 10.

Waste heat recovery is not applicable where there is no demand that matches the production curve. However, it is being applied an increasing number of cases, and many of these can be found outside of the installation, see Co-generation, Section 3.4, and Chapter 5.

Techniques for cooling and the associated BAT are described in the CV BREF, including techniques for maintenance of heat exchangers.

**20. BAT to maintain the efficiency of heat exchangers by both (see Section 3.3.1.1 and the CV BREF):**

a) monitoring the efficiency periodically

b) preventing or removing fouling according to the fluids exchanging heat.

### 4.3.4 Cogeneration

There is significant interest in cogeneration currently, supported at Community level by the adoption of Directive 2004/8/EC on the promotion of cogeneration, and Directive 2003/96/EC on energy taxation, as well as by various national level policies and incentives. Relatively small scale plant may now be economically feasible, and incentives may also be available. In many cases, cogeneration has been successfully installed due to the assistance of local authorities. See Sections 3.4 and Chapter 5.

Utilities modelling, Section 2.7.5 can assist the optimisation of the generation and heat recovery systems, as well as managing the selling and buying of surplus energy.

**21. BAT is to seek possibilities for cogeneration, inside and/or outside the installation (with a third party).**

*Applicability: The co-operation and agreement of a third party is not within the control of the operator, and therefore may not be within the scope of an IPPC permit.*

*In general, cogeneration can be considered when:*

- *the demands for heat and power are concurrent*
- *the heat demand (on-site and/or off-site), in terms of quantity, temperature etc. that can be met using heat from the CHP plant, and no significant heat demand reductions can be expected.*

*Section 3.4 discusses the application of cogeneration, the different types of cogeneration (CHP) plant and their applicability in individual cases.*

*The successful implementation may depend on a suitable fuel price in ratio to the price of electricity. In many examples, the assistance of local authorities*

### 4.3.5 Electric power supply

Quality of the electrical power supply and the manner in which the power is used can affect energy efficiency, see Section 3.5. This may be difficult to understand and is often overlooked. There are often energy losses as unproductive power inside the installation and in the external supply grid. There can also be loss of capacity in the installation's electrical distribution system, leading to voltage drops, causing overheating and premature failure of motors and other equipment. It may also lead to increased charges bought in electricity (see Section 3.5).

22. **BAT is to correct the power factor to 0.95 or above by using the techniques in Table 4.3, according to applicability (see Section 3.5.1):**

| Technique | Applicability |
|---|---|
| Installing capacities in the AC circuits to decrease the magnitude of reactive power | All cases. Low cost and long lasting, but requires skilled application |
| Minimising the operation of idling or lightly loaded motors | All cases |
| Avoiding the operation of equipment above its rated voltage | All cases |
| When replacing motors, using energy efficient motors (see Section 3.6) | At time of replacement |

**Table 4.3: Power factor correction techniques**

23. **BAT is to check the power supply for harmonics and apply filters if required (See Section 3.5.2).**

24. **BAT is to optimise the power supply efficiency by using the techniques in Table 4.4, according to applicability (see Section 3.5.3):**

| Technique | Applicability |
|---|---|
| Using high efficiency transformers | At time of replacement |
| Oversizing power supply cables | At shut down or when locating or relocating equipment. |
| Placing equipment with high current demand as close as possible power source (e.g. transformer) to supply | When locating or relocating equipment. |

**Table 4.4: Power factor correction techniques**

## 4.3.6 Electric motor driven sub-systems[20]

Electrical motors are widely used in industry. Replacement by electrically efficient motors (EEMs) and variable speed drives (VSDs) is one of the easiest measures when considering energy efficiency. However, this should be done in the context of considering the whole system the motor sits in, otherwise there are risks of:

- losing the potential benefits of optimising the use and size of the systems, and subsequently optimising the motor drive requirements
- losing energy if a VSD is applied in the wrong context.

Key systems using electric motors are:

- compressed air (CAS, see Section 3.7)
- pumping (see Section 3.8)
- ventilation (see Section 3.10)
- cooling (see the CV BREF).

**25. BAT is to optimise electric motors in the following order (see Section 3.6):**

1) optimise the entire system the motor(s) is part of (e.g. cooling system, see Section 1.5.1)

2) then optimise the motor(s) in the system according to the newly-determined load requirements, by applying one or more of the techniques in Table 4.5, accordingly to applicability

| **Driven system energy savings measure** | **Typical savings range** | **Applicability** |
|---|---|---|
| **System installation or renewal** | | |
| Using energy efficient motors (EEM) | 2 - 8 % | Lifetime cost benefit |
| Correct sizing | 1 - 3 % | Lifetime cost benefit |
| Energy efficient motor repair (EEMR) or replacement with EEM<br>*TWG: is this the same as rewinding?* | 0.5 - 2 % | At time of repair |
| Rewinding: avoid rewinding and replace with EEM, or use EEMR, or use certified rewinding contractor (EEMR) | >1 % | At time of repair |
| Installing variable speed drives (VSD) | 10 - 50 % | According to load. Note in multi-machine systems with variable load systems (e.g. CAS) it may be optimal to use only one VSD motor |
| Installing high-efficiency transmission/reducers | 2 - 10 % | Lifetime cost benefit |
| Using:<br>• direct coupling where possible<br>• synchronous belts or cogged V-belts in place of V belts<br>• helical gears in place of worm gears | 0 - 45 % | All<br>*TWG: is this different to row above* |
| Power quality control | 0.5 - 3 % | Lifetime cost benefit |
| **System operation and maintenance** | | |
| Lubrication, adjustments, tuning | 1 - 5 % | All cases |

**Table 4.5: Electric motors: energy efficiency measures (see Section 3.6)**

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[20] In this document 'system' is used to refer to a set of connected items or devices which operate together for a specific purpose, e.g. ventilation, CAS. See the discussion on system boundaries in Sections 1.3.4 and 1.5.1. These systems usually include motor sub-systems (or component systems).

3) when the energy-using systems have been optimised, then optimise the remaining (non-optimised) motors according to Table 4.5 and the following criteria:

    ii) prioritise the remaining motors running more than 2000 hrs per year for replacement with EEMs

    iii) electric motors driving a variable load operating at less than 50 % of capacity more than 20 % of the time and operating for more than 2000 hours a year should be equipped with variable speed drives.

*TWG: are these good applicability criteria?*

### 4.3.7 Compressed air systems (CAS)

Compressed air is widely used as either part of a process or to provide mechanical energy. It is widely used where there is risk of explosion, ignition, etc. In many cases, it is difficult to assess its mechanical efficiency (such as blowing, moulding, mixing), and it is used because of its properties. In some cases, where driving small turbines, e.g. assembly tools, and there are no health and safety constraints, it has a low overall efficiency and replacement with other drives may be considered (see Section 3.7).

**26. BAT is to optimise compressed air systems (CAS) using the techniques in Table 4.6, according to the applicability:**

| Energy savings measure | % applicability (1) | % gains (2) | Potential contribution (3) | Applicability | Cross - reference |
|---|---|---|---|---|---|
| **System installation or renewal** | | | | | |
| Development of an improvement strategy by analysing and benchmarking the system performance, and improving the system operation and management | | | | All | 2.2.2, 2.2.3, 2.6, 3.7.1 |
| Overall system design, including multi-pressure systems | 50 % | 9 % | 4.5 % | New or significant upgrade | 3.7.1 |
| Improvement of drives (high efficiency motors) | 25 % | 2 % | 0.5 % | Most cost effective in small (<10 kW) systems | 3.5, 3.7.2, 3.7.3 |
| Improvement of drives (Speed control) | 25 % | 15 % | 3.8 % | Applicable to variable load systems. In multi-machine installations, only one machine should be fitted with a variable speed drive. The estimated gain is for overall improvement of systems, whether single or multi-machine | 3.5, 3.7.2 |
| Upgrading of compressor | 30 % | 7 % | 2.1 % | New or significant upgrade | 3.7.1 |
| Use of sophisticated control systems | 20 % | 12 % | 2.4 % | All | 3.7.4 |
| Recovering waste heat for use in other functions | 20 % | 20 % | 4.0 % | Note that the gain is in terms of energy, not of electricity consumption, since electricity is converted to useful heat | 3.7.5 |
| Improved cooling, drying and filtering | 10 % | 5 % | 0.5 % | This does not include more frequent filter replacement (see below) | |
| Reducing frictional pressure losses (for example by increasing pipe diameter) | 50 % | 3 % | 1.5 % | New or significant upgrade, or part of ongoing improvements | 3.7.1 |
| Optimising certain end use devices | 5 % | 40 % | 2.0 % | All | 3.7.1 |
| **System operation and maintenance** | | | | | |
| Reducing air leaks | 80 % | 20 % | 16.0 % | Largest potential gain. All cases. | 3.7.6 |
| More frequent filter replacement | 40 % | 2 % | 0.8 % | Review in all cases | |
| | | **TOTAL** | **32.9 %** | Depends on baseline | |

Table legend: (1) % of CAS where this measure is applicable and cost effective
(2) % reduction in annual energy consumption
(3) Potential contribution = Applicability * Reduction

**Table 4.6: Compressed air systems: Energy efficiency measures**

For a correctly dimensioned and well-managed installation, operating at nominal flow and a pressure of 7 bars, the following can be taken as a benchmark efficiency (it takes into account different compressor technologies):

$$85\ \text{Wh/Nm}^3 < \text{SEC} < 130\ \text{Wh/Nm}^3$$

## 4.3.8 Pumping systems

Pumping systems account for nearly 20 % of world electrical consumption and 25 to 50 % of energy usage in certain industrial plants. Some 30 % to 50 % of the energy consumed by pump systems may be saved through equipment or control system changes (see Section 3.8).

**27. BAT is to optimise pumping systems by using the techniques in Table 4.7, according to applicability (see Section 3.8):**

| Technique | Applicability | Comments |
|---|---|---|
| **DESIGN** | | |
| Development of an improvement strategy by analysing and benchmarking the system performance, and improving the system operation and management | All cases | See Sections 2.2.2, 2.2.3, 2.6, 3.8 |
| Avoid oversizing when selecting a pump | All cases | Largest single source of pump energy wastage |
| Design of distribution system (see below) | | |
| **CONTROL and MAINTENANCE** | | |
| Control and regulation system | All cases | |
| Shut down unnecessary pumps | All cases | |
| Use of variable speed drives | Lifetime cost benefit<br>Not applicable where loads are constant | |
| Use of multiple pumps (staged cut in) | When the pumping load is less than half the maximum single capacity | |
| Regular maintenance. Where unplanned maintenance becomes excessive, check for:<br>• cavitation<br>• wear<br>• wrong type of pump | All cases<br>Repair or replace as necessary | |
| *Note:* Throttle control on centrifugal pump discharge | Not BAT. Widely used. Consider alternatives above. | Less energy wasteful than no control or by-pass control |
| **DISTRIBUTION SYSTEM** | | |
| Avoid using too many valves | All cases at design and installation (including changes) | |
| Avoiding using too many bends (especially tight bends) | All cases at design and installation (including changes) | |
| Ensuring the pipe work diameter is not too small (correct pipe work diameter) | All cases at design and installation (including changes) | |

**Table 4.7: Pumping systems: Energy efficiency measures**

## 4.3.9 Drying and separation processes

The separation of (usually) a solid from a liquid may be carried out by one or more stages. By optimising the process steps required to achieve the required product, substantial energy savings can be achieved. Energy efficiency may be optimised by using two or more techniques in combination (see Section 3.9).

**28. BAT to optimise drying and separation processes by using the techniques in Table 4.8 according to applicability:**

| Technique | Applicability | Comments | Cross-reference |
|---|---|---|---|
| **DESIGN** | | | |
| Development of an improvement strategy by analysing and benchmarking the system performance, and improving the system operation and management | All cases | | 2.2.2, 2.2.3, 2.6, 3.9 |
| Selecting the optimum separation technology or combination of techniques (below) to meet the specific process equipments | All cases. | | 3.9.1 |
| Use of surplus heat from other processes | Depends on the availability of surplus heat in the installation (or from third party) | Drying is a good use for surplus heat | 3.9.1 |
| Use a combination of techniques | Consider in all cases | May have production benefits, e.g. improved product quality, increased throughput | 3.9.1 |
| Mechanical processes | Process dependant. May be best considered in combination with other techniques. | Energy consumption can be several orders of magnitude lower, but will not achieve high % dryness | 3.9.2.1 |
| Thermal processes | Widely used, but efficiency can be improved by considering other options in this table | Convective heat driers may have be the option with the lowest energy efficiency | 3.9.2.2 |
| Radiant processes | Can be easily retrofitted.<br>Compact<br>Reduces need for air extraction<br>IR limited by substrate dimensions.<br>High cost, needs lifetime cost benefit assessment | More efficient heating. Can boost production throughput coupled with convection or conduction | 3.9.2.3 |
| Superheated steam | Any direct dryers can be retrofitted with superheated steam<br>High cost, needs lifetime cost benefit assessment<br>High temperature may damage product | Heat can be recovered from this process and/or recovered | 3.9.2.5 |
| **CONTROL** | | | |
| Process automation in thermal separation processes | All cases | Savings of between 5 and 10 % can be achieved compared with using traditional empirical controllers | 3.9.2.4 |

**Table 4.8: Drying and separation systems: Energy efficiency measures**

### 4.3.10 Ventilation systems

Ventilation systems are essential for many industrial installations to function. It:

- protects staff from pollutant and heat emissions within premises
- guarantees production and quality.

Requirements may be dictated by health, safety and process considerations (see Section 3.10)

29. **BAT is to optimise ventilation systems by using the techniques in Table 4.9 according to applicability:**

| Energy savings measure | Potential contribution | Comments | Cross-reference |
|---|---|---|---|
| Development of an improvement strategy by analysing and benchmarking the system performance, and improving the system operation and management | | All | 2.2.2, 2.2.3, 2.6, 3.10 |
| Overall system design<br>Identify areas and fit areas for<br>• general ventilation<br>• specific ventilation<br>• process ventilation | | New or significant upgrade<br>Consider for retrofit on lifetime cost benefit | 3.10.1 |
| Optimise the number, shape and size of intakes | | New or upgrade | 3.10.1 |
| Use fans of<br>• high efficiency<br>• designed to operate at optimal rate | | Cost effective in all cases | 3.10.1, 3.10.2 |
| Managing airflow, including considering dual flow ventilation | | New or significant upgrade | 3.10.1 |
| Air system design:<br>• ducts are sufficient size<br>• circular ducts<br>• avoid long runs and obstacles such as bends, narrow sections | 10 % increase in diameter can save 72 % of input power | New or significant upgrade | 3.10.1 |
| Optimise electric motors, including consider installing VSD | | All cases. Cost effective retrofit<br>See also motor Section 3.6 and BAT 22 | 3.10.1, 3.10.2 |
| • Use of automatic control systems<br>• Integrate with centralised technical management systems | | All new and significant upgrades. Cost effective and easy upgrade in all cases | 3.10.1, 3.10.2 |
| Integration of air filters into air duct system and energy recovery devices to avoid energy losses on expelled air | | New or significant upgrade<br>Consider for retrofit on lifetime cost benefit | 3.10.1, 3.10.2 |
| **Maintenance** | | | |
| Stop or reduce ventilation where possible | | All cases | 3.10.2 |
| Ensure system is airtight, check joints | | All cases | 3.10.2 |
| Check system is balanced | | All cases | 3.10.2 |
| Managing airflow: adjustment | 20 % reduction in flow can save 50 % fan power consumption | All cases | 3.10.2 |
| Air filtering, optimise:<br>• recycling efficiency<br>• pressure loss<br>• regular filter cleaning/replacement | | All cases | 3.10.2 |

**Table 4.9:Heating and ventilation: energy efficiency techniques**

### 4.3.11 Lighting

Health and safety at work is usually the key driver for lighting systems requirements. The energy of lighting systems can be optimised according to the use requirements, see Section 3.11.

**30. BAT is to optimise artificial lighting systems by using the techniques in Table 4.10 according to applicability (see Section 3.11.1):**

| Technique | Applicability |
|---|---|
| **DESIGN** | |
| Development of an improvement strategy by analysing and benchmarking the system performance, and improving the system operation and management | All cases. See Sections 2.2.2, 2.2.3, 2.6, 3.11.1 |
| Determine the specification of illumination requirements | All cases |
| Analysis of lighting quality | All cases |
| Design of time of day use that does not expend unnecessary energy | All cases |
| Selection of lamp types and fixtures according to requirements | Cost benefit on lifetime basis |
| Integration of space planning to lighting design | New or upgraded systems |
| **OPERATION, CONTROL, MAINTENANCE** | |
| Maintenance of lighting systems to minimize energy wastage | All cases |
| Training of building occupants to utilize lighting equipment in most efficient manner | All cases |

**Table 4.10: Lighting: energy efficiency techniques**

# 5 ADDITIONAL TOOLS AND TECHNIQUES TO PROMOTE ENERGY EFFICIENCY IN INDUSTRYBEST AVAILABLE TECHNIQUES

## 5.1 Introduction

This section deals with tools and issues that are not part of the IPPC Directive, but support the achievement of energy efficiency in industry, such as EU and Member State policy support tools and mechanisms.

Where possible, a standard structure is used to outline each motivation tool, as shown in Table 5.1:

| Type of information considered | Type of information included |
|---|---|
| Description | Short description of the tool with pictures, flow sheets, etc. which illustrate the tool |
| Achieved environmental benefits | The energy savings achieved as a result of implementing this tool |
| Cross-media effects | (if any) |
| Operational data | Performance data on energy and other consumptions (raw materials and water) and on emissions/wastes. Any other useful information on how to operate, maintain and control the technique, including safety aspects, operability constraints of the technique, output quality, etc. |
| Applicability | Can this tool be used in all kinds of organisations or are there some restrictions? What restrictions? |
| Economics | What are the costs of implementing the tool? And who is paying them? Is it private or is it totally/partly state subsidised? |
| Driving force for implementation | The reasons the tool has been developed, used by industry, the target group, etc. |
| Example | Examples of implementation of this tool |
| Reference information | Sources of information and literature containing more details |

**Table 5.1: Information template for energy efficiency motivation tools**

It is often said that industry will address energy efficiency as part of their normal business, constantly seeking to lower costs. However, sometimes an energy saving measure which may be highly significant from the environmental point of view but which is not so attractive from the economic point of view, possibly having a long payback period or even a net cost over time, is unlikely to be implemented unless there is some specific driving force to do so.

### 5.1.1 Tax deductions for energy saving investments

**Description**

An investor can benefit a reduction of annual gains in a tax declaration. This reduction equals between 13.5 and 20 % of the total investment cost for energy saving investments for the year during which the investments have been made. The exact percentage is determined yearly depending on the consumption index.

**Achieved environmental benefits**

**Cross-media effects**

**Operational data**

**Applicability**

The tool has been developed and is implemented by the Federal Department of Finance in Belgium. Industry and private companies use this tool to reduce their taxes. Cannot be used by public entities.

**Economics**

The cost is a reduction of state tax income.

**Driving force for development and implementation**

The driving force for development and implementation is to stimulate energy saving investments.

**Results of implementing this tool**

Total effect has not yet been estimated.

**Example**

Belgium

**Reference information**

[30, Maes, 2005]

## 5.1.2 Ecology premium

**Description**
A company can receive a premium equal to a part of the investment in some energy saving techniques. This premium can be paid by the government to the company. The premium is organised around a 'limiting list of technologies' which gathers some 600 different technologies. The list specifies the technique and the extra cost compared to regular techniques.

The premium depends on the size and type of the company, and covers a maximum of 40 % of the extra cost. Small and medium-sized companies can benefit higher percentages than large companies. Extra increases of the premium are foreseen for companies with for instance an ISO 14001 label or an EMAS label. The premium has a ceiling of EUR 1.8 million.

**Achieved environmental benefits**
Results not yet estimated.

**Cross-media effects**

**Operational data**

**Applicability**
The tool is restricted to private companies and organisations. Any technologies which are not represented in the ‘limitative list of technologies’ can still be taken into account, but are regarded individually on the basis of the reductions of $CO_2$ emissions

**Economics**
Costs are covered by the Ministry of the Flemish Community

**Driving forces for implementation**
The Flemish government developed the tool to stimulate investments in environmentally friendly techniques and energy saving techniques. The tool is implemented by the Ministry of the Flemish Community

**Examples**
Ecology Premium in Belgium.

**Reference information**
[30, Maes, 2005]

### 5.1.3 Support for demonstration projects in energy technology

**Description**

The application of an innovative technique to reduce energy consumption or to generate energy, can receive support. This support covers at most 50 % of the cost of the innovative part of the investment.

**Achieved environmental benefits**

Energy savings as a result of this tool have not yet been estimated.

**Cross-media effects**

**Operational data**

**Applicability**

Any physical or legal person can apply for this support.

**Economics**

The tool is publicly financed by the Ministry of the Flemish Community (BE).

**Driving force implementation**

The tool was developed to stimulate the implementation of innovative energy technologies. This tool is being designed and implemented by the Ministry of the Flemish Community. Every project is being monitored in order to provide correct information about the value of the innovative technique for the future.

Organisations use the tool to finance innovative techniques and any physical or legal person can apply for this support.

**Examples**

This tool was set up in 1992 and has supported 65 pilot projects for innovative energy systems to date in the Flemish Community.

**Reference information**

[30, Maes, 2005]

### 5.1.4 Cogeneration certificates (blue certificates)

**Description**

The Flemish Regulation Entity for the electricity and gas market (VREG) awards certificates to owners of cogeneration plants according to the age of the cogeneration plant and the amount of produced energy. A certificate represents 1 MWh saved primary energy. The Cogeneration plant needs to be a 'qualitative cogeneration plant', which means that at least a 5 % reduction of primary energy consumption is achieved compared to production in separate gas-fired power and heat plants.

These certificates can be sold to electricity suppliers, as these suppliers need to provide yearly a sufficient amount of CHP certificates to the Flemish Regulation Entity. The CHP-certificate has therefore a market value.

**Achieved environmental benefits**

The tool was only recently implemented in Flanders, so results are not yet available.

**Cross-media effects**

**Operational data**

**Applicability**

This tool creates a restricted market. On the one hand, the tool is used by energy producers operating a qualitative cogeneration plant, and on the other hand it is used by electricity suppliers.

**Economics**

The implementation of the tool, the follow-up and all related activities of the Flemish regulation entity for the electricity and gas market (VREG) are publicly financed. The electricity suppliers pay electricity producers for the certificates.

**Driving force for implementation**

The tool has been developed to promote the installation of cogeneration plants in Flanders. The Flemish regulation entity for the electricity and gas market (VREG) is responsible for the implementation, the follow-up and the control of the system.

The CHP certificates play a major role in the decision process for the construction of a cogeneration plant. The additional income can be substantial and provides income during the first operating years. The tool is financed by the electricity suppliers.

**Examples**

**Reference information**

[30, Maes, 2005]

### 5.1.5 Energy planning regulation

**Description**

The recent regulation concerning energy planning obliges every environmental permit demand to be accompanied by an energy plan or an energy study. An energy plan is a tool to elaborate proper energy planning and is requested with the demand of an environmental permit for a new site. An energy study accompanies a demand for renewal of an existing permit. Environmental permits are to be renewed at least every three years, or when the industrial site undergoes changes.

Both the energy plan and the study should contain a list of possible energy saving measures, with a calculated internal rate of return (IRR). The regulation requires the industrial site to implement every mentioned energy saving measures with an IRR of 15 % or higher.

**Achieved environmental benefits**

This has only recently been developed and implemented. The interactions with the benchmarking process and the audit covenant allow a synergetic approach.

**Cross-media effects**

**Operational data**

**Applicability**

Every site with a primary energy consumption>0.5 PJ per year should have a energy plan.

Sites which engaged in the benchmarking process automatically meet the criteria of the energy planning regulation.

**Economics**

The regulation obliges companies to take efficient energy saving measures during the validity period of their environmental permit.

Sites with a primary energy consumption between 0.1 and 0.5 PJ need to join an energy plan with the demand for renewal of their environmental permit.

New sites with an energy consumption larger then 0.1 PJ, or sites undergoing changes which induce an increase in primary energy consumption of at least 10 TJ need to provide an energy study.

**Driving force for development and implementation**

The tool has been developed in order to take energy consumption and energy efficiency into account in environmental permits.

The ministry of the Flemish community concluded that a BAT-approach to promote energy-efficiency was not the optimal solution. The description of an obligatory structure for an energy planning leaves the necessary flexibility for the companies to improve their energy efficiency according to their priorities.

**Examples**

Flemish Community.

**Reference information:**

[30, Maes, 2005]

### 5.1.6 Benchmarking covenant

**Description**
Large industrial companies can engage themselves in the benchmarking process. The industrial companies commit themselves to belong to the world top of energy efficiency, while as a compensation government guarantees not to impose other measures as, for instance, an energy or $CO_2$ levy.

The system is managed by the verification office. Companies finance improvements in their industrial complex privately. The auditors of the verification office control the energetic performance of the companies.

**Achieved environmental benefits**
The industries should achieve and maintain an energy efficiency within the world 10 % best before 2012. The current benchmarking structure covers a period from 2002 to 2012.

Trends show that under the influence of the benchmarking covenant, the energy efficiency of the different sites will be on average 7.8 % better by 2012.

**Cross-media effects**

**Operational data**

**Applicability**
Industrial sites can enter the benchmarking process in three cases:

- the sites have an annual primary energy consumption of higher than 0.5 PJ
- the sites have an annual primary energy consumption of less than 0.5 PJ, but they can apply the benchmarking procedure
- the sites have an annual primary energy consumption of less than 0.5 PJ but they are obligatory participants to the European emissions trading system.

**Economics**
The activities of the responsible Benchmarking Commission and the Verification Office are being funded by the regional authorities. Energy audits and energy saving measures in the participating companies are financed privately.

**Driving force for implementation**
The tool has been developed to allow the industry to adapt in a flexible way to increase energy efficiency restrictions. The tool is targeted to the industrial sites with the largest energy consumptions, and is implemented by the Ministry of the Flemish Community.

In return for the efforts to increase energy efficiency, the regional authorities engage themselves amongst others to:

- avoid any further energy or $CO_2$ related taxation
- attribute the necessary emission rights to enable the companies to comply with the European rules for emissions trading.

**Examples**

**Reference information**
[30, Maes, 2005]

### 5.1.7 Audit covenant

**Description**

Industrial companies with a yearly primary energy consumption of between 0.1 and 0.5 PJ, who did not engage themselves in the benchmarking process can enter the audit covenant. The industrial companies commit themselves to perform a complete energy plan and to implement all economically feasible measures to improve energy efficiency. As compensation, the government guarantees not to impose other measures as, for instance, an energy or $CO_2$ levy.

The system is managed by the verification office. Companies finance improvements in their industrial complex privately. The auditors of the verification office control the energetic performance of the companies.

**Achieved environmental benefits**

The tool was implemented during the course of 2005, so results have not yet been determined.

**Cross-media effects**

**Operational data**

**Applicability**

The industrial sites can enter the audit covenant if their yearly primary energy consumption is between 0.1 and 0.5 PJ, and if they did not engage themselves in the benchmarking process.

**Economics**

The activities of the responsible benchmarking commission and the verification office are being funded by the regional authorities. Energy audits and energy saving measures in the participating companies are financed privately.

**Driving force for development and implementation**

The tool has been developed to allow the industry to adapt in a flexible way to increasing energy-efficiency restrictions.

**Examples**

**Reference information**

[30, Maes, 2005]

### 5.1.8 Energy saving certificates (white certificates)

**Description** The mechanism is imposed on electricity and natural gas distributors, operating without competition. The electricity and natural gas distributors serving more than 100 000 end users have to demonstrate that they have directly or indirectly achieved energy savings through action involving the end users. The accepted savings and measures are set by the Italian government as annual targets.

The distributors may achieve the savings by action involving the consumer, either directly, through a subsidiary company or purchasing the TEE (white certificate) from an Energy Service Company (ESCO) or from another distributor (even one not subject to the obligation). The structure of system is described in Figure 5.1.

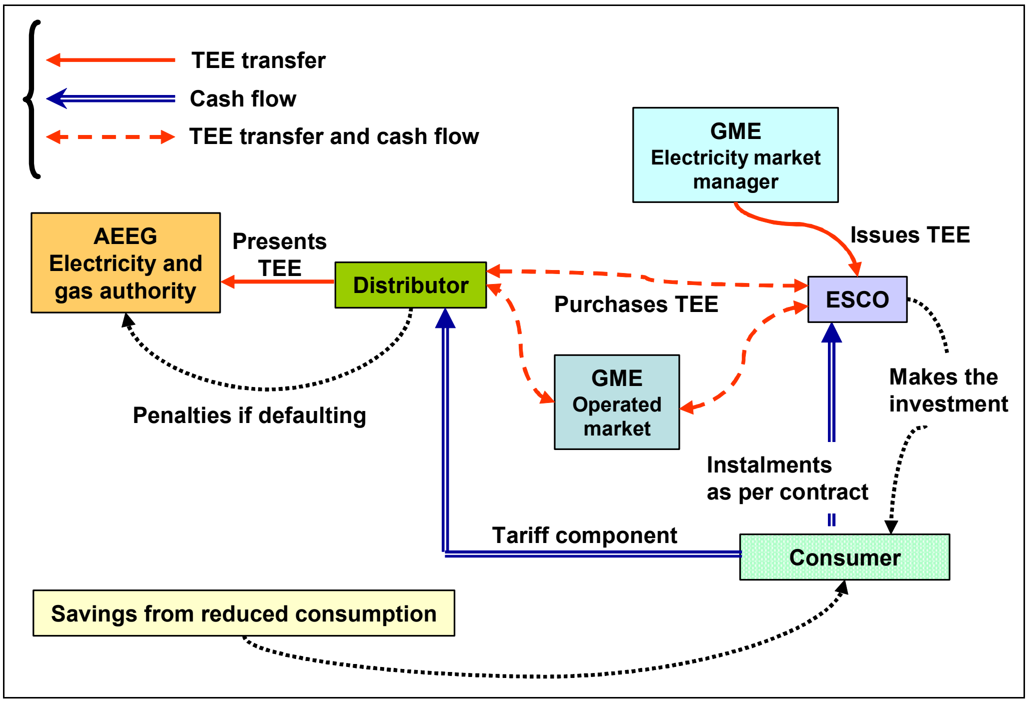

**Figure 5.1: Mechanism when an ESCO is involved**

The certificates issued are of three different types:

- type 1 certifies savings in electrical energy
- type 2 in natural gas, and
- type 3 in other fuels.

At least 50 % of the titles presented by the distributors must be for savings in the energy distributed.

Today there are twenty two energy saving evaluation forms for technological units issued as follows:

- either standardised type (calculations of the savings are based only on the number of units installed, on their power or on their dimensions) or
- analytical (a set of values is required for calculation of the saving).

**Achieved environmental benefits**

### Cross-media effects

### Operational data

A similar mechanism has been tried in the United Kingdom, but applied only to electricity vendors, on the basis of domestic consumers supplied and with only actions involving these last covered.

In Italy, the mechanism is not yet in full operation, given that the market in efficiency certificates (TEE) is not yet open, and therefore it cannot be said whether or how it will function. However, inclusion of ESCO as organisations that can obtain efficiency titles has created great interest in energy service companies, whose numbers have risen dramatically.

### Applicability

In Italy, it has been decided to consider all demand side energy efficiency actions involving end users as admissible.

### Economics

Part of the costs incurred - which are accompanied by a reduction in revenues resulting from the lower quantity of energy distributed - distributors subject to the obligation can recover EUR 100 per TEE through distribution tariffs, in the case of certificate types 1 and 2.

This sum is spread over all the consumers served by distributors[21], not only those subject to the obligation. In this way the costs are imposed directly on consumers.

That part of the costs not recovered in this way will probably be recovered through a lower annual decrease in distribution tariffs (which are subject to a price cap in Italy) for all clients of distributors subject to the obligation.

The mechanism is therefore paid for by consumers served by distributors, to the benefit of those who perform the interventions, whether or not served by distributors.

Although end users cannot receive incentives directly through the mechanism, they can nevertheless gain advantages if they are the physical site of the intervention and therefore beneficiaries of the associated energy and cost saving. In general, it will be possible to carry out the actions at a lower cost than would be possible in the absence of the mechanism.

### Driving force for development and implementation

- Kyoto protocol and saving primary energy by strengthening energy savings among end users
- raise the awareness and knowledge of end users.

### Examples

### Reference information

[50, Forni, 2005]

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[21] Consumers not served by distributors but connected directly to the grid, are not subject to the recovery of costs through tariffs. Large industrial users are typically not served by distributors.

### 5.1.9 Energy saving agreements

**Description**

*TWG: Is this still wanted?*

Energy saving agreements between companies and governments are broadly used in Member States. This section will give an overview of the situation and then handle energy saving agreements at company level, dealing with how companies implement them as a part of a management system. This will include:

- contents of energy saving agreements
- energy saving agreements in energy efficiency implementation
- examples from Member States.

### 5.1.10 Energy Service Company (ESCO)

**Description**

Attention in energy policy debates is frequently drawn to the untapped potential for energy savings. The failure to leverage this potential is attributable not so much to economic factors as to structural shortcomings and a lack of information on the part of energy users. Energy performance contracting (EPC) via energy service providers, or energy service companies (ESCOs or ESCos) can assist in leveraging energy savings.

The ESCo will identify and evaluate energy-saving opportunities and then recommend a package of improvements to be paid for through savings. The ESCo will guarantee that savings meet or exceed annual payments to cover all project costs - usually over a mid- to long term contract of e.g. seven to 10 years. If savings don't materialize, the ESCo pays the difference.

The importance of energy services is underscored by the EU Directive on energy end-use efficiency and energy services of April 5, 2006 (2006/32/EC), which defines energy services as follows:

*'Energy service is the physical benefit, utility or good derived from a combination of energy with energy efficient technology and/or with action, which may include the operations, maintenance and control necessary to deliver the service, which is delivered on the basis of a contract and in normal circumstances has proven to lead to verifiable and measurable or estimable energy efficiency improvement and/or primary energy savings'*

An energy service provider can supply for example, the following types of energy, depending upon the application involved:

- thermal energy (building heating, steam, process heat, process water, hot water)
- cooling (coolant water, district cooling)
- electricity (light and power from cogeneration plants or photovoltaic installations
- air (compressed air, ventilation, air conditioning).

**Achieved environmental benefits**

Energy savings. The savings to be achieved will be the subject of the EPC.

**Cross-media effects**

None reported.

### Operational data
The ESCO may perform the following tasks (in chronological order):

identification of energy saving potential
feasibility study
determination of objectives and Energy Savings Agreement signature
preparing the project for implementation
management of the construction and putting the finished work into operation
evaluation of the environmental and economical parameters actually achieved.

### Applicability
Widely used in the US for ten – twenty years. Increasingly used in the EU.

### Economics
The basic contractual clause of the energy performance contract (EPC) concluded between the enterprise and the ESCO consists in the obligation of ESCO to achieve, for the enterprise, both the predefined reduction of environmental load and contracted economical parameters of the project. Such required parameters may be agreed upon on an individual basis and often include the following:

- the guaranteed level of annual savings on energy costs as compared to the existing condition
- guaranteed return on investment resulting from the future savings on energy costs and other financial effects (incl. the sale of surplus emission permits, income from the sale of 'white certificates', savings on service and maintenance costs, etc.)
- guaranteed level of reduced emissions
- guaranteed reduced level of the consumption of primary fuels;
- other guaranteed parameters as agreed upon between the ESCO and the enterprise.

### Driving force for implementation
The following drivers can be met by successful energy performance contracting (EPC) through and ESCO:

provision of the necessary skills to respond to the following drivers (see Section 2.3)
the method and correct performance of the energy audit
proposed concept of changes comprising more options and a feasibility study
selection of the optimum option taking account of the expected future development of the enterprise
selection of the best performing energy saving technologies and processes
provision of necessary funds for the installation of energy efficient technologies
selection of the suppliers of particular components
correctness of the procedures used for the installation of energy efficient technologies.
achievement of the planned energy performance and economical efficiency.

### Examples
See Annex 11.

### Reference information
[Czech Republic, SPF Group]
[DE, LFUG]
http://www.esprojects.net/en/energyefficiency/financing/esco

## 5.2 Demand management

**Description**
This usually refers to managing electricity demand. It is important to distinguish the cost saving elements from the energy saving measures.

In most EU (and many other) countries there is a complex pricing structure for electricity, depending on the peak quantity used, the time at which power is drawn from the grid and other factors, such as the possibility to accept a cap on the quantity supplied. Peak usage in an installation may mean that part of the electricity units used will be charged at a premium rate and/or contract cost penalties may be incurred. Control of this is necessary, and moving or smoothing the peaks will result in a cost saving. However, this may not decrease the total energy units used, and there is no increase in physical energy efficiency.

Peaks in demand can be can be avoided or controlled for example, by:

- for equipment with large power demand, such as large motors, converting connections from star to delta for low loadings, using automatic delta to star converters, using soft-starters, etc.
- using control systems to stagger the start up of equipment e.g. a the start of shifts (see Section 2.7.5)
- changing the time of day processes causing spikes in electrical usage are used.

**Achieved environmental benefits**

**Cross-media effects**
May not achieve energy savings.

**Operational data**
Some examples of high instantaneous demands are:

- on start up of equipment with significant power usage, e.g. large motors
- start up of a shift, with several systems starting, e.g. pumps, heating
- processes such as heat treatment, with high energy demands, particularly if not used constantly.

High instantaneous demands can also cause energy losses by distorting the even pattern of the AC cycles of the phases and loss of useful energy. See Harmonics, Section 3.5.2.

**Applicability**
Consider in all installations.

Control can be manual (e.g. changing the time of day a process is used), simple automatic controls (e.g. timers), or linked to more sophisticated energy and /or process management systems (see Section 2.7.5)

**Economics**
Unnecessary power consumption and peaks in power result in higher costs.

### Driving force for implementation

Cost saving.

### Examples

Widely used.

### Reference information

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[183, Bovankovich, 2007]
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## 5.3 Transport systems

Depending on the industry sector, transport may be a significant energy consumer in a company. Energy consumption of company transport can be reduced by good ‘transport management’ which is part of the overall management system of the company.

The selection of the most environmentally effective transport system depends on the type of product. Road transport is used widely, but rail and ship are used for bulk materials, and pipelines for liquids and gases.

*(TWG: data has only been supplied for road transport)*

### 5.3.1 Road transport

**Description of the energy efficiency technique**
To manage energy efficiency of transport, generate long-term improvements in fuel performance, monitor and target successfully and measure the improvements from any initiative it is necessary to collect and analyse data.

The following four steps are essential in a fuel management programme:

- setting up a system of collecting data
- making sure data are collected accurately
- cleaning up data
- analysing and interpreting the data.

The main options for data collection are to:

- collect data manually and key into a spreadsheet or database
- collect data from the fuel pump and upload electronically into a computer spreadsheet or database
- use fuel cards, and either use their reporting systems, or upload them electronically into a computer spreadsheet or database
- monitor the amount of fuel that actually goes through each vehicle’s engine by using an onboard device. Many modern trucks with electronically controlled engines can be specified with an optional onboard data system that can capture this information
- fit a separate fuel flow-meter and link this to a proprietary onboard computer to record the fuel consumption.

Allied to the appropriate download methods and computer software, the two last options noted in the bullet point list above should give good quality data about individual vehicle and driver performance, and both have the advantage of measuring fuel actually going into the engine, rather than being dispensed from the storage tank. However, this approach does have some limitations. It does not control bulk fuel stock, i.e. reconciling deliveries and the amount of fuel dispensed.

It is also expensive because the fuel measurement system is replicated on each vehicle rather than a single system monitoring the whole fleet. So it may be necessary to treat onboard devices as an addition to the basic pump system rather than as a replacement for it.

It is important to retain raw data (i.e. fuel used and distance travelled) to avoid creating errors by averaging fuel consumption figures. In other words, when averaging the fuel consumption over any period the totals of distance and volumes should be used.

Factors which influence fuel consumption

- the vehicle is obviously one of the largest factors in determining the fuel performance (the make/model, the specification, the age of the vehicle, the condition of the vehicle, operational details, equipment and products used, e.g. lubricants, aerodynamics, etc.)
- the driver who drives the vehicle is considered to be the biggest single influence on fuel consumption. Issues concerning the driver start with recruitment and selection and continue through training, motivation and involvement
- the load being carried will naturally affect a vehicle's fuel performance. Total weight is the critical factor, and this often changes during the journey as deliveries are made
- The optimisation of size, shape and loading of containers holding the products is crucial (see Annex 12)
- the weather also influences fuel consumption. This needs to be remembered when comparing data gathered during different weather conditions. Wind, rain, sleet, snow, etc. can all have a great impact on performance
- the type of road will play its part, with narrow winding roads giving worse fuel consumption than straight dual carriageways. Slow and tortuous routes through hilly terrain will drag down the fuel performance of even the best vehicles
- fuel acquisition. The two main properties of fuel are the amount of energy it contains, which is highly dependent on the density of the fuel, and the ease with which it combusts.

Monitoring
There are five key elements in monitoring:

1. Measure consumption regularly - this will generally involve the production of regular (preferably weekly) records of the fuel consumption of each vehicle.

2. Relate consumption to output - normally the distance travelled by the vehicle is related to the fuel used (e.g. km per litre), but this can be further refined. Other measures include fuel per tonne km (i.e. fuel used to carry one tonne of payload a distance of one km).

3. Identifying present standards - analyse fuel consumption figures for similar vehicles undertaking similar types of work over a representative period of time. Arrive at an approximate fuel consumption standard for each vehicle. This would not constitute an 'efficient' standard but rather a base or actual figure.

4. Report performance to the individuals responsible - fuel consumption data should be reported regularly to people who have some influence on fuel consumption. These would normally include drivers, engineers and middle and senior management.

5. Take action to reduce consumption - Taking a systematic overview of fuel use often generates ideas for reducing consumption. Comparing the fuel efficiencies of different vehicles is likely to reveal anomalies in their performance. Identifying the causes of these anomalies should enable good practice to be distinguished from bad, and allow steps to be taken to eliminate poor performance.

Tightening up operating practices and vehicle maintenance in this way often leads to savings even without the introduction of specific fuel saving measures.

Historical fuel information is crucial to plan and implement energy saving measures. Fuel information for each vehicle at raw data level is kept throughout its life, in much the same way as its servicing records.

Reporting

The following standard reports are useful in fuel management:

- bulk tank stock reconciliation
- individual vehicle and driver fuel performance
- exception reports.

Vehicle performance can then be grouped by type, such as:

- articulated/rigid
- gross vehicle weight
- manufacturer/model
- age
- work done.

Driver performance can also be grouped, using categories such as shift, type of work and trained or untrained. The usual periods for measurement are weekly, monthly and year to date.

Useful comparisons are against:

- targets
- previous period(s) for the analysis of trends
- same period last year
- other depots, bearing in mind regional and operational differences
- similar vehicles
- industry averages, e.g. road test reports, published cost tables.

These data are used at least by the following people:

- the senior management (a concise overview, summaries and exception reports)
- the transport manager (the fuel saving initiatives, investigate specifics and carry out individual performance reviews)
- the driver trainer (plan a fuel-related training programme and set up discussions with drivers, who themselves need to start monitoring their own performance
- engineering and maintenance staff (monitor and analyse the fuel figures).

There are many areas of fuel management which can be subject to key performance indicators and targets. The easiest are where measurement is straightforward and unaffected by too many outside factors. Examples would include bulk tank fuel losses where the figures might be measured each week with a requirement to investigate and resolve any losses over a target figure.

More complicated measures are involved in the monitoring system of vehicle performance. The simplest way is merely to take current performance and demand an improvement. However, this takes into consideration only what has actually been achieved rather than what is achievable.

Where the routes, loads, etc. are consistent, it may be possible to set up standard targets by route, using your best driver to set the target for everyone else, although obviously, this will not take into account seasonal and other such outside influences, and therefore will need to be interpreted very carefully.

A more sophisticated approach is to use energy intensity as an indicator. For freight transport this is defined as fuel consumed/(tonnes carried x distance travelled) and would normally be measured as litres per tonne kilometre.

### Achieved environmental benefits

The reduction of fuel consumption has a direct correspondence to the environmental effects. Reducing consumption not only represents avoided costs but also fewer tonnes of $CO_2$ are produced.

### Cross-media effects

None reported.

### Operational data

Driving in a fuel-efficient manner can improve safety and benefit the vehicle's driveline, brakes and tyres as well. So there could well be a reduction in the costs of accidents, maintenance, repairs and downtime.

Some operators have even used the improvement in fuel economy as a commercial tool to emphasise the contribution they are making to the environment.

Thorough communication between drivers and management is part of a good fuel programme. If handled well, there is a potential spin-off here, because it might lead to better understanding and some barriers being broken down. Some organisations have used fuel efficiency as a means of changing the driver culture.

### Applicability

This fuel management technique can be applied to industries that have road transport fleets.

### Economics

The combination of the crude oil price and fuel excise duty has meant that fuel has generally proved to be a fast-rising operating cost. This means that any investment in good fuel management now may well pay even greater dividends in the future.

The achievement of fuel savings invariably requires an investment in time, effort or money - and often all three. Financial expenditure on such things as fuel monitoring equipment or better vehicles is easy to quantify, but do not forget hidden costs, such as investment in management, clerical and operative time, which may be more difficult to pin down.

### Driving force for implementation

Cost savings - not all energy conservation measures are equally cost effective. Different measures will be better suited to different types of operation. However, it is important that anyone wishing to reduce their fuel consumption should proceed in a systematic manner, rather than introduce new practices on a piecemeal basis. It is practical that energy consumption of transport is included in a generic energy management system/structure.

### Examples

VICO SA located in Vic-sur-Aisne (France)
See Annex 12

### Reference information

[94, ADEME, 2005], [103, Best practice programme, 1996]

# 6 EMERGING TECHNIQUES FOR THE ENERGY EFFICIENCY

## 6.1 High temperature air combustion technology (HiTAC)

**Description**

The main feature of the HiTAC technique is a novel combustion mode with a homogeneous flame temperature, without the temperature peaks of a conventional flame, in a substantially extended combustion zone.

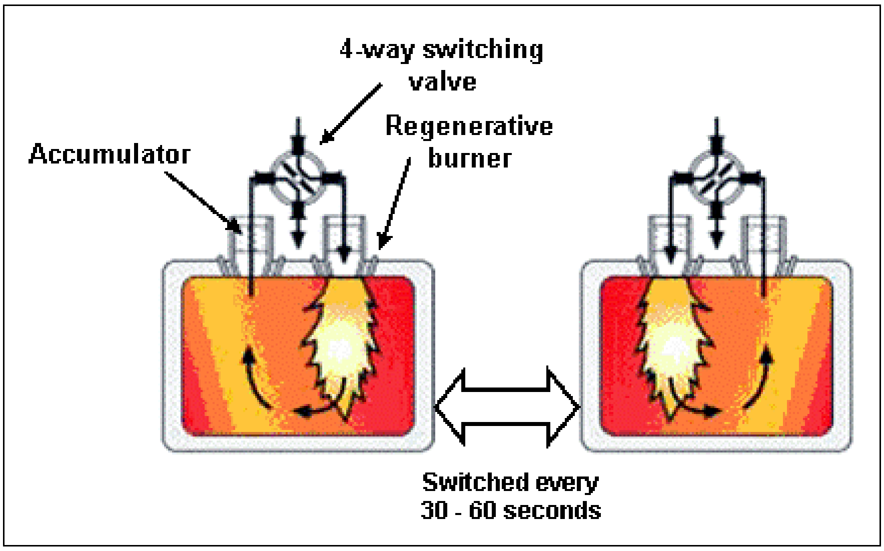

**Figure 6.1: Working principle for regenerative burners**
**[17, Åsbland, 2005]**

In HiTAC technology the combustion air is preheated to a very high temperature before it is injected into the furnaces at high speed. This high temperature air combustion allows fuel to burn completely at very low oxygen levels. Previously, complete combustion was thought impossible at these levels. This method makes the flame longer, slows combustion speeds, and keeps combustion temperatures lower than those of conventional high temperature combustion furnaces, thus effecting lower $NO_X$ emissions as well as more uniform flame temperature distribution. The flame turns distinctively pale green during the process.

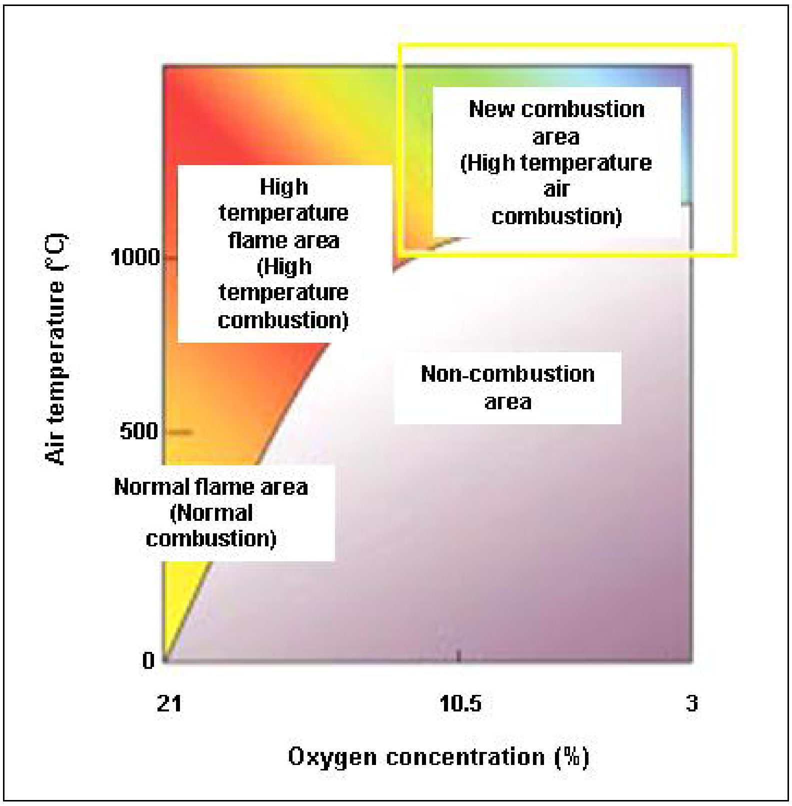

**Figure 6.2: Different regions of combustion**
**[17, Åsbland, 2005]**

There are two types of HiTAC burners: one-flame burners and two-flame burners. A one-flame HiTAC burner is characterised by a single flame created by one fuel nozzle surrounded by air inlets and flue-gas outlets. This single flame develops along the axis of the fuel-jet nozzle during cooling and heat periods. Fuel is supplied continuously through the same nozzle and in this way a single flame can be formed with a permanent position. The position of the flame remains almost unchanged between heating and cooling periods, as the regenerators are located around the nozzle of the fuel-jet.

In a two-flame HiTAC burner there are two separated high cycle regenerative burners. The two burners are located in the walls of the furnace and work in tandem. A set of valves change the direction of the air and flue-gases according to the required switching time. Normally there are several pairs of burners working together. In this type of HiTAC, the flame is shifted from one burner to another in accordance with the switching time between the heating and cooling periods of the regenerator.

Besides the regenerative HITAC burner the FlOX burner (Flameless Oxidation) should be mentioned.

### Achieved environmental benefits

According to the tests, the HiTAC burner has reached 35 % higher efficiency than a conventional jet burner. Besides the higher efficiency, the HiTAC burner's large flame volume resulted in an increased heat transfer coefficient. The fuel used in the test was LPG (propane). The energy balance for both the HiTAC and the conventional burner is shown below in Figure 6.3:

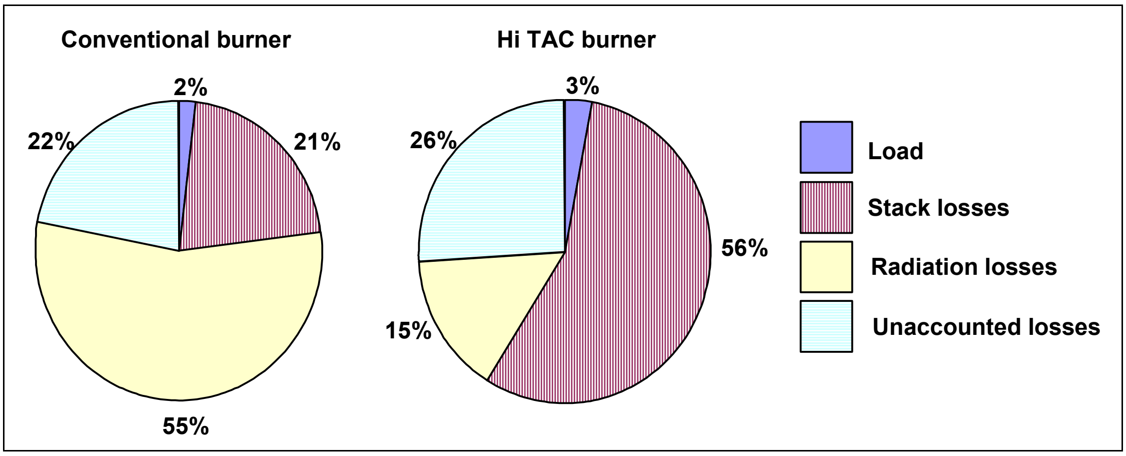

**Figure 6.3: The net heat output of test furnaces resulted by both conventional and HiTAC burners [17, Åsbland, 2005]**

The $NO_X$ formation, for fuels not containing nitrogen, is basically a function of temperature, oxygen concentration, and residence time. In a typical heating furnace, residence time is usually long enough to enable the generation of $NO_X$. For HiTAC technology, the basic issues for reducing $NO_X$ are to lower the peak temperature of the flame and to reduce the oxygen concentration. The technology solution to reduce $NO_X$ in HiTAC is exhaust gas recirculation (EGR).

A HiTAC furnace allows:

- high energy utilisation efficiency or decreased $CO_2$ emission, for several sectors, especially when preheated air may be used
- more uniform temperature profile
- low $NO_X$ emissions
- smaller flue-gas tubes
- even temperature distribution
- enhanced heat transfer
- increased product quality productivity
- longer lifetime of furnace and tubes.

### Cross-media effects

The important constraint of state-of-the-art recuperative/regenerative burner technology is the conflict between technologies designed to reduce emissions and focusing on energy efficiency. Due to high temperatures of the preheated air, conventional flames have a high peak temperature which leads to a strong increase of $NO_X$ emissions.

The enhanced heat transfer with HiTAC burners could result in higher productivity (capacity) and/or lower investment costs for certain industrial sectors such as metallurgy.

Could result in higher productivity and /or lower investment is not a solid basis for a decision, include commercial figures, cost effectiveness of this example should be calculated.

### Operational data

For HiTAC's industrial application, fuel nozzles and combustion air nozzles are arranged on the burner at a certain distance from each other. Fuel and high temperature air are injected directly into the furnace at high velocity. Thereby the gas in the zone near the burner is thoroughly mixed and its partial pressure of oxygen is lowered. The combustion stability of fuel directly injected into this zone with oxygen at low partial pressure is possible if the temperature in the preheated air exceeds the auto ignition temperature of the fuel.

In the industrial furnace, the combustion air can be obtained at a temperature of 800 –1350 C using a high performance heat exchanger. For example, a modern regenerative heat exchanger switched in the high cycle can recover as much as 90 % of the waste heat. Thus, a large energy saving is achieved.

The paragraph on operational data is missing information about operation and maintenance of the HiTac burners move this section to an annex Information about lifespan, outages, maintenance is required

90 % is too high

### Applicability

Heating furnaces, where regenerative burners using HiTAC technology could be applied, are widespread in high temperature industry sectors throughout Europe; these sectors include iron and steel, glass, brick and tiles, non-ferrous metals and foundries. For instance, 5.7 % of the primary energy demanded in the EU is used in the steel industry. Energy also accounts for a high proportion of production costs in these industries.

*TWG: The HiTAC technology can be used only for specific furnaces and only natural gas. It is not suitable for low calorific gases such as biogenic gases, by product gases etc. Additionally it is not suitable for RTH (Radial tube heating). HiTAC burners do not exist for every specific demand and has not yet stand the test on an industrial scale. Not applyable for l.c. gases. Not applyable for RTH furnaces. The applicability must be checked for every specific process. There are only few installations using the Process under production conditions. HiTAC burners also have quite high demands for purity of the athmosphere: if process gas is utilized, there will be too much dust in the furnace to use HiTAC burners*

*General remark: There is a big difference between combustion devices and heating furnaces in the industry. Technology for special processes is discussed in the sectoral BREF. Applicability: Not for industrial furnaces (which are discussed in the sectoral BFEF's)*

*The paragraph on applicability only discusses the potential for HiTac application move this section to an annex This paragraph should also address retrofit opportunities and bottlenecks*

*Change the wording concerning applicability These sectors include iron and steel, brick and tiles, non ferrous metals, foundries and at the moment potentially few applications in small glass furnaces. Due to extreme conditions required by glass melting, it is supposed that this sector could be one of the most difficult area to implement this new technique.*

*Chapter about applicability of the HiTAC technology must be modified, because it gives too optimistic view about applicability. These burners cannot substitute any burner in the cited industrial sectors. It should be stated, that HiTAC burners cannot necessarily be added to existing process lines, because the furnaces need to be designed so that the burners will fit in. It is stated in this paragraph in which industrial sectors HiTAC technology could be.applied, but there is no comment on how many of the burners in these sectors could possibly be substituted by HiTAC technology. HiTAC burners also have quite high demands for purity of the athmosphere: if process gas is utilized, there will be too much dust in the furnace to use HiTAC burners*

**Economics**

A drawback with these burners is the investment cost. However, the payback rates are often below 3 to 5 years. Therefore higher productivity in the furnace and low emission of nitrogen oxides are important factors to be included in the cost/benefit analysis.

**Driving force for implementation**

Higher productivity in the furnace and lower emission of nitrogen oxides are important factors.

**Examples**

The steel manufacture SSAB Tunnplåt AB in Borlänge, Sweden.

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# 7 CONCLUDING REMARKS

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# GLOSSARY

| ENGLISH TERM | MEANING |
|---|---|
| **Symbols** | |
| µm | micrometre (1 µm = $10^{-6}$ m) |
| ~ | around; more or less |
| °C | degree Celsius |
| $_0$ | ambient conditions |
| ΔT | temperature difference (increase) |
| ε | exergetic efficiency |
| σ | entropy production J/K |
| η | thermal efficiency |
| | |
| **A** | |
| A = | amp (ampere). The SI symbol for electrical current. |
| AC | alternating current |
| AEA | Austrian Energy Agency , also AEA Technology (a UK consultancy) |
| aka | also known as |
| AN | Ammonium Nitrate ($NH_4NO_3$) |
| API | American Petroleum Institute |
| APQP | Advanced Product Quality Planning (APQP) is a structured method of defining and establishing the steps necessary to assure that a product satisfies customers. It facilitates communications with all actors involved to assure that all needed steps are completed on time. |
| ASTM | a large international standards organisation. Originally the American Society for Testing and Methods, now ASTM International |
| AT | Austria |
| atm | atmosphere (1 atm = 101325 $N/m^2$) |
| av | average |
| | |
| **B** | |
| bar | bar (1.013 bar = 1 atm) |
| bara | bar absolute |
| barg | bar gauge which means the difference between atmospheric pressure and the pressure of the gas. At sea level, the air pressure is 0 bar gauge, or 101325 bar absolute |
| BAT | best available techniques |
| BOOS | burner out of service |
| Bq | Becquerel ($s^{-1}$) – activity of a radionuclide |
| BREF | BAT reference document |
| BTEX | benzene, toluene, ethyl benzene, xylene |
| | |
| **C** | |
| C | velocity m/s |
| C | specific heat of an incompressible substance J/(kgK) |
| $C_4$ stream | a mixture of molecules all having four carbon atoms. Usually<br>• butadiene ($C_4H_6$)<br>• butene-1, butene-2 and isobutylene ($C_4H_8$)<br>• N-butanes and isobutene ($C_4H_{10}$) |
| CAS | compressed air system |

| ENGLISH TERM | MEANING |
|---|---|
| cavitation | when a volume of liquid is subjected to a sufficiently low pressure it may rupture and form a cavity. This phenomenon is termed cavitation inception and may occur behind the blade of a rapidly rotating impellor or propeller or on any surface vibrating underwater (or in fluids generally) with sufficient amplitude and acceleration. Cavitation is usually an undesirable occurrence. In devices such as propellers and pumps, cavitation causes a great deal of noise, damage to components, vibrations, and a loss of efficiency. Although the collapse of cavities is a relatively low energy event, it is highly localized and can even erode metals such as steel. The pitting caused by the collapse of cavities produces great wear on components and can dramatically shorten a propeller or pump's lifetime (wikipedia) |
| CC | combined cycle |
| CCGT | combined cycle gas turbine |
| CCP | coal combustion products |
| CEM | continuous emission monitoring |
| CEMS | continuous emission monitoring system |
| CEN | European Committee for Standardisation |
| CENELEC | European Committee for Electrotechnical Standardisation |
| CFB | circulating fluidised bed |
| CFBC | circulating fluidised bed combustion |
| CFC | chlorofluorocarbon is a compound consisting of chlorine, fluorine, and carbon. CFCs are very stable in the troposphere. They move to the stratosphere and are broken down by strong ultraviolet light, where they release chlorine atoms that then deplete the ozone layer |
| CHP | combined heat and power (cogeneration) |
| CIP | clean-in-place system |
| cm | centimetre |
| COD | chemical oxygen demand: the amount of potassium dichromate, expressed as oxygen, required to chemically oxidise at approx. 150 C substances contained in waste water |
| COP | coefficient of performance (e.g.for heat pumps) |
| COPHP | coefficient of performance of heat pump cycle |
| COPR | coefficient of performance of refrigeration cycle |
| $c_p$ | specific heat at constant pressure J/(kgK) |
| continual improvement | it is a process of improving year by year the results of energy management, increasing efficiency and avoiding unnecessary consumptions |
| cross-media effects | the calculation of the environmental impacts of water/air/soil emissions, energy use, consumption of raw materials, noise and water extraction (i.e. everything required by the IPPC Directive) |
| CTM | chicken tikka masala |
| $c_v$ | specific heat at constant volume J/(kgK) |
| cv | control volume |
| | |
| **D** | |
| d | day |
| DBB dry bottom boiler. The most common type of coal | burning furnace in the electric utility industry is the dry, bottom pulverized coal boiler. When pulverized coal is burned in a dry, bottom boiler, about 80 per cent of the unburned material or ash is entrained in the flue-gas and is captured and recovered as fly ash. The remaining 20 per cent of the ash is dry bottom ash, a dark gray, granular, porous, predominantly sand size minus 12.7mm material that is collected in a water |
| DC | direct current |
| DCS | distributed control systems |
| DDCC | direct digital combustion control |
| DE | Germany |
| DH | district heating |
| DK | Denmark |
| | |

| ENGLISH TERM | MEANING |
|---|---|
| **E** | |
| E | exergy J |
| e | exergy per unit mass J/kg |
| E2, EE | energy efficiency |
| E2MS | energy efficiency management system |
| EA | energy audit |
| EAM | energy audit model |
| EDTA | ethylenediamine tetraacetic acid |
| EEI | energy efficiency index |
| EFF | motor efficiency classification scheme created by the European Commission and the EU motor manufacturers (CEMEP). There are three class levels of efficiency, known as EFF1 (high efficiency motors), EFF2 (standard efficiency motors) and EFF3 (poor efficiency motors), applying to low voltage two- and four-pole motors with ratings between 1.1 and 90 kW |
| EGR | exhaust gas recirculation |
| EIF | energy intensity factor |
| EII | energy intensity index |
| EIPPCB | European IPPC Bureau |
| ELV | emission limit value |
| EMAS | European Community Eco-Management and Audit Scheme |
| emission | the direct or indirect release of substances, vibrations, heat or noise from individual or diffuse sources in the installation into the air, water or land |
| emission limit values | the mass, expressed in terms of certain specific parameters, concentration and/or level of an emission, which may not be exceeded during one or more periods of time |
| EMS | environment management system |
| EN | European Norm (standard) |
| energy audit | the process of identification of the energy consumptions, the conservation potentials and appropriate efficiency practices |
| energy performance | the amount of energy consumed in relation with obtained results. The lower the specific energy consumption, the higher the energy performance |
| EO | energy output |
| EOP, EoP | end-of-pipe |
| EPER | European pollutant emission register |
| ESCO | energy service company |
| $E_T$ | total energy J |
| EU-15 | 15 Member States of the European Union |
| EU-25 | 25 Member States of the European Union |
| | |
| **F** | |
| f | saturated liquid |
| FAD | free air delivery |
| FMEA | failure mode and effects analysis. A systematic process for identifying potential (design and) process failures before they occur, with the intent to eliminate them or minimize the risk associated with them. |
| FBC | fluidised bed combustion |
| FBCB | fluidised bed combustion boiler |
| $f_g$ | difference in property for saturated vapour and saturated liquid |
| FI | Finland |
| FR | France |
| | |
| **G** | |
| g | acceleration of gravity m/s$^2$ |
| g | gram |
| g | saturated gas |
| G | giga $10^9$ |
| GJ | gigajoule |

| ENGLISH TERM | MEANING |
|---|---|
| green certificate | a market-based tool to increase use of renewables. Green certificates represent the environmental value of renewable energy production. The certificates can be traded separately from the energy produced |
| GT | gas turbine |
| GTCC | gas turbine combined cycle |
| GW | gigawatt |
| GWh | gigawatt hours |
| $GWh_e$ | gigawatt hours electrical |
| GWP | global warming potential |
| | |
| **H** | |
| H | enthalpy J |
| h | specific enthalpy J/kg |
| h | hour |
| hammer | fluid hammer, see water hammer |
| harmonics | a sine-shaped component of a periodic wave or quantity having a frequency that is an integral multiple of a fundamental frequency. It is a disturbance in clean power |
| HCV | higher calorific value, higher combustion value |
| HF | high frequency radiation. Electromagnetic radiation possessing wavelengths in the radio wave range, i.e. from approximately 1 to 1 x 102 metres |
| HFO | Heavy fuel oil |
| HP steam | high pressure steam: steam with a pressure much greater than atmospheric |
| HiTAC | High Temperature Air Combustion Technology |
| HMI | human machine interface |
| HP | high pressure |
| HPS | high pressure steam |
| HRSG | heat recovery steam generator |
| HV | high voltage. The International Electrotechnical Commission and its national counterparts (IEE, IEEE, VDE, etc.) define high voltage circuits as those with more than 1000 V for alternating current and at least 1500 V for direct current, and distinguish it from low voltage (50–1000 V AC or 120–1500 V DC) and extra low voltage (<50 V AC or <120 V DC) circuits. This is in the context of the safety of electrical apparatus. |
| HVAC | heating, ventilation and air conditioning |
| Hydrotreater | hydrodesulfurisation (HDS) unit is widely used in the petroleum refining industry and are also often also referred to as a hydrotreater. It uses a catalytic chemical process to remove sulphur (S) from natural gas and from refined petroleum products such as gasoline or petrol, jet fuel, kerosene, diesel fuel, and fuel oils. |
| Hz | herzt |
| | |
| **I** | |
| IE | Ireland |
| IEA | International Energy Agency |
| IEF | Information Exchange Forum (informal consultation body in the framework of the IPPC Directive) |
| IGCC | integrated gasification combined cycle |
| installation | a stationary technical unit where one or more activities listed in Annex I of the IPPC Directive are carried out, and any other directly associated activities which have a technical connection with the activities carried out on that site and which could have an effect on emissions and pollution |
| IPPC | integrated pollution prevention and control |
| IR | infra-red radiation. Electromagnetic radiation possessing wavelengths between visible light and radio waves, i.e. from approximately 1x 10 |
| IRR | internal rate of return |
| ISO | International Standardisation Organisation |
| ISO 14001 | ISO Environmental Management Standard |

| ENGLISH TERM | MEANING |
|---|---|
| IT | Italy |
| | |
| **J** | |
| J | joule |
| JRC | Joint Research Centre |
| | |
| **K** | |
| K | kelvin (0 °C = 273.15 K) |
| kcal | kilocalorie (1 kcal = 4.19 kJ) |
| kg | kilogram |
| kJ | kilojoule (1 kJ = 0.24 jkcal) |
| KN | kinetic energy J |
| kPa | kilopascal |
| kt | kilotonne |
| kWh | kilowatt-hour (1 kWh = 3600 kJ = 3.6 MJ) |
| | |
| **L** | |
| l | litre |
| LCP | large combustion plant |
| LCV | lower calorific value, lower combustion value |
| Lean, Lean manufacturing | a generic process management philosophy derived mostly from the Toyota Production System (TPS) but also from other sources. It is renowned for its focus on reduction of the original Toyota 'seven wastes' in order to improve overall customer value. Lean is often linked with Six Sigma because of that methodology's emphasis on reduction of process variation (or its converse smoothness). |
| LFO | light fuel oil (lighter than HFO) |
| LP | low pressure |
| LP steam | low pressure steam: steam with a pressure less than, equal to, or not greatly above, atmospheric |
| LPG | liquid petroleum gas |
| LPS | low pressure steam |
| lux | (symbol: lx) The SI unit of illuminance. It is used in photometry as a measure of the intensity of light, with wavelengths weighted according to the luminosity function, a standardized model of human brightness perception. In English, "lux" is used in both singular and plural |
| LVOC | large volume organic chemicals (BREF) |
| | |
| **M** | |
| m | mass |
| m | metre |
| M | mega $10^6$ |
| m/min | metres per minute |
| $m^2$ | square metre |
| $m^3$ | cubic metre |
| MBPC | model-based predictive control |
| mg | milligram (1 mg = $10^{-3}$ gram) |
| MIMO | multi-input, multi-output |
| MJ | mega joule (1 MJ = 1000 kJ = $10^6$ joule) |
| mm | millimetre (1 mm = $10^{-3}$ m) |
| monitoring | process intended to assess or to determine the actual value and the variations of an emission or another parameter, based on procedures of systematic, periodic or spot surveillance, inspection, sampling and measurement or other assessment methods intended to provide information about emitted quantities and/or trends for emitted pollutants |
| MP | medium pressure |
| MPS | medium pressure steam |
| MS | member state |

| ENGLISH TERM | MEANING |
|---|---|
| MSA | measurement systems analysis. A method using experiment and mathematics to determine how much the variation within the measurement process contributes to overall process variability |
| Mt | megatonne (1 Mt = $10^6$ tonne) |
| mV | millivolt (mV), $10^{-3}$ volt, 1/1000 of a volt |
| MV | Megavolt (MV) $10^6$volts, 1 000 000 volts |
| MVR | mechanical vapour recompression system. A type of heat pump. |
| $MW_e$ | megawatts electric (energy) |
| $MW_{th}$ | megawatts thermal (energy) |
| | |
| **N** | |
| N | nozzle |
| n.a. | not applicable OR not available (depending on the context) |
| n.d. | no data |
| ng | nanogram (1 ng = $10^{-9}$ gram) |
| NG | natural gas |
| $Nm^3$ | normal cubic metre (101325 kPa, 273 K) |
| NMHC | non-methane hydrocarbons |
| NMVOC | non-methane volatile organic compounds |
| NPSH | net positive suction head. It shows the difference, in any cross-section of a generic hydraulic circuit, between the pressure and the liquid vapour pressure in that section. In pump operation, two aspects of this parameter are called respectively NPSH (a) Net Positive Suction Head (available) and NPSH (r) Net Positive Suction Head (required), where NPSH(a) is computed at pump inlet port, and NPSH(r) is the NPSH limit the pump can withstand without cavitating. Retrieved from "http://en.wikipedia.org/wiki/NPSH" |
| | |
| **O** | |
| OECD | Organisation for Economic Co-operation and Development |
| OFA | overfire air |
| operator | any natural or legal person who operates or controls the installation or, where this is provided for in national legislation, to whom decisive economic power over the technical functioning of the installation has been delegated |
| ºR | degree Rankin |
| Otto cycle | four stroke engine |
| | |
| **P** | |
| P | peta $10^{15}$ |
| P, p | pressure |
| Pa | pascal |
| PCB | polychlorinated benzenes |
| PCDD | polychlorinated-dibenzo-dioxins |
| PCDF | polychlorinated-dibenzo-furans |
| PDCA | plan-do-check-act -cycle |
| PFBC | pressurised fluidised bed combustion |
| PFBC | pressurised fluidised bed combustion |
| PI | process-integrated |
| PID | proportional integral derivative control |
| PLC | programmable logic controls |
| pollutant | individual substance or group of substances which can harm or affect the environment |
| ppb | parts per billion |
| ppm | parts per million (by weight) |
| ppmvd | parts per million by volume for dry gases |
| PT | potential energy |
| | |

| ENGLISH TERM | MEANING |
|---|---|
| **Q** | |
| Q | heat J |
| $\dot{Q}$ | heat rate |
| QMS | quality management system |
| | |
| **R** | |
| R | gas constant J/(gK) |
| R&D | research and development |
| $R_u$ | universal gas constant J/(molK) |
| Right First Time | a quality management system. A concept integral to total quality management, where there is a commitment to customers not to make mistakes. The approach requires employees at all levels to commit to, and take responsibility for, achieving this goal. Quality circles are sometimes used as a method to help in this process. |
| | |
| **S** | |
| S | entropy J/K |
| s | specific entropy J/(kgK) |
| s | second |
| saturated steam | steam at the temperature of the boiling point which corresponds to its pressure |
| SAVE programme | EC energy efficiency programme |
| SCADA | supervisory control and data acquisition |
| SE | Sweden |
| sensible heat | heat energy that is transported by a body that has a temperature higher than its surroundings via conduction, convection, or both. Sensible heat is the product of the body's mass, its specific heat capacity and its temperature above (an inferred) reference temperature. (Wikipedia) |
| SG | steam generator |
| Six Sigma, 6 sigma, 6-σ | a quality system where the likelihood of an unexpected failure is confined to six standard deviations (where sigma is the standard deviation, and 6-σ equates to 3.4 defects per million) |
| SME | small to medium sized enterprise |
| specific consumption | consumption related to a reference basis, such as production capacity, or actual production (e.g. mass per tonne or per unit produced) |
| SPOT | steam plant optimization tool |
| superheated steam, | steam heated to a temperature higher than the boiling point corresponding to its pressure. It cannot exist in contact with water, nor contain water, and resembles a perfect gas; also called surcharged steam, anhydrous steam, and steam gas. |
| | |
| **T** | |
| t | time |
| t | metric tonne (1000 kg or $10^6$ gram) |
| T | temperature |
| T | tera $10^{12}$ |
| t/yr | tonne(s) per year |
| TAC | total allowable concentration |
| TEE | abbreviation for white certificate in Italy, see white certificate |
| TQM | Total Quality Management (TQM) is a comprehensive and structured approach to organizational management that seeks to improve the quality of products and services through ongoing refinements in response to continuous feedback. TQM processes are divided into four sequential categories: plan, do, check, and act (the PDCA cycle). |
| TWG | technical working group |
| thyristor drive | a motor and controller combination including the drive shaft, where AC supply current is regulated by a thyristor phase control to provide variable voltage to a DC motor. |

| ENGLISH TERM | MEANING |
|---|---|
| top management | the person or group of people of the highest authority that direct the company or part of it |
| | |
| **U** | |
| U | internal energy |
| u | internal energy per unit of mass J/kg |
| UHC | unburned hydrocarbons |
| UPS | an uninterruptible power supply. A device which maintains a continuous supply of electric power to connected equipment by supplying power from a separate source when utility power is not available. |
| | |
| **V** | |
| V | volume |
| v | specific volume $m^3$/kg |
| V | volt. The SI derived unit of electric potential difference or electromotive force. |
| VA | volt-ampere: in electrical terms, means the amount of apparent power in an alternating current circuit equal to a current of one ampere at an emf of one volt. It is equivalent to watts for non-reactive circuits (in industry usually found as kV: 10 kVA = 10,000 watts capability (where the SI prefix k equals kilo); 10 MVA = 10,000,000 watts capability (where M equals mega) |
| VAM | vinyl acetate monomer |
| VOCs | volatile organic compounds. Compounds that have high enough vapour pressures to significantly vaporise under ambient conditions. Includes a wide range of molecules such as aldehydes, ketones and hydrocarbons. Commonly found in solvents for paint, printing inks, adhesives, some fuels, etc. See STS BREF. |
| vol-% | percentage by volume. (Also % v/v) |
| Volute | spiral casing housing the rotor in a centrifugal pump |
| | |
| **W** | |
| W | work J |
| Water hammer | (or, more generally, fluid hammer) is a pressure surge or wave caused by the kinetic energy of a fluid in motion when it is forced to stop or change direction suddenly. It depends on the fluid compressibility where there are sudden changes in pressure. For example, if a valve is closed suddenly at an end of a pipeline system a water hammer wave propagates in the pipe.<br>Steam heating systems for buildings may also be vulnerable to water hammer. In a steam system, water hammer most often occurs when some of the steam condenses into water in a horizontal section of the steam piping. Subsequently, steam picks up the water, forms a "slug" and hurls it at high velocity into a pipe elbow, creating a loud hammering noise and greatly stressing the pipe. This condition is usually caused by a poor condensate drainage strategy. (Wikipedia) |
| wet steam, | steam which contains water held in suspension mechanically; also called misty steam. |
| WBB | wet bottom boiler. A boiler that contains a wet bottom furnace. It is a kind of boiler used for pulverised fuel firing. In wet bottom boiler the bottom ash is kept in a molten state and tapped off as a liquid. The ash hopper in wet - bottom furnaces contains quenching water. 3. When the molten slag comes in contact with the quenching water, it fractures instantly, crystallizes, and forms pellets. Wet bottom boilers are preferred for low volatile coals that produce a lot of ash. But it has higher investment costs and higher maintenance costs. So it is less build. (Wikipedia) |

| ENGLISH TERM | MEANING |
|---|---|
| white certificate | a market-based tool to get energy savings for some category of operators (distributors, consumers, etc.) coupled with a trading system for energy-efficiency measures resulting in energy savings. The savings would be verified and certified by the so-called “white” certificates. |
| WI | waste incineration |
| wt-% | percentage by weight. (Also % w/w) |
| W-t-E | waste to energy |
| | |
| **X** | |
| x | molar fraction, quality |
| | |
| **Y** | |
| yr | year |
| | |
| **Z** | |
| Z | compressibility factor |
| z | elevation, position m |

# 8 ANNEXES

## ANNEX 1 CASE STUDIES OF THERMODYNAMIC IRREVERSIBILITIES

*Note to TWG: These annexes have not been edited. We are aware that you have made comments on some of these (those in black text), and these will be dealt with before the final document. Please comment on those in blue text.*

### Case 1. Throttling devices

Throttling devices are very common in industry and are used to control and reduce pressure mainly through valves. Since the throttling process is isenthalpic (where the enthalpy up and down flows are equal) no energy is lost and according to the first law of thermodynamics, its efficiency is optimal.

However, this is a typical mechanical irreversibility which reduces pressure and increases the entropy of the fluid, without giving any additional benefit. Consequently, exergy is lost and the fluid is less capable of producing energy in a turbine expansion process for instance.

Therefore, if the point is to reduce the pressure of a fluid, it is desirable to tend to isentropic expansions providing useful work as an additional result through turbines. If this is not possible, the working pressure should always be the highest possible because this will avoid the use of compressors or pumps for fluid transportation (additional useful energy).

A very frequent practice in industrial installations is to keep the pressure at the inlet of the turbine at the design conditions. This usually implies the use and abuse of admission valves to control the turbine. According to the second law, it is better to have flotation of the pressure specifications (sliding pressure) and to keep the admission valves completely open.

As a general recommendation, valves should be sized as large as possible. A satisfactory throttling process can be achieved with a pressure drop of 5 - 10 % at maximum flow instead of 25 – 50 % as it happened in the past, where valves were small sized. Of course the pump driving the fluid must be also sized according to the variable conditions.

Finally, it must be stressed that pipes also act as throttling devices, decreasing the pressure of the fluid flowing through them. Therefore, a good design with good materials and few obstacles such as unnecessary valves, elbows, bows, etc. will limit the exergy losses across the process.

In any case, it is clear that an exergy accounting that considers all the energy levels existing in the plant must be performed, because from the first law point of view, irreversibilities are very difficult or impossible to identify.

**Numerical example**

During a unit commissioning in a power plant, a steam extraction coming from the high pressure turbine ($P = 40$ kg/cm$^2$, $T = 350$ ºC) is used in order to feed a turbopump.

Since the turbopump operates at an inlet pressure of 8 kg/cm$^2$, the steam coming from the high pressure turbine must be throttled (see Figure 8.1). In the following thermodynamic example, variables of the steam are evaluated at the inlet and outlet of the valve. The process is sketched on the T-s and h-s diagrams (see Figure 8.2) and the exergy flow is obtained when the nominal flow is 45 000 kg/h.

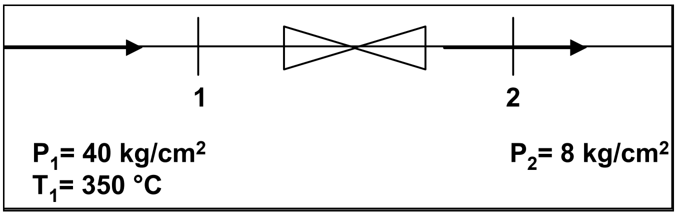

**Figure 8.1: Steam throttling process**

## Solution

The first law of thermodynamics reveals that the process is isenthalpic since no work or heat transfer is associated with the throttling process:

| | |
|---|---|
| $0 = m_1(h_2-h_1) \Rightarrow h_2 = h_1$ | Equation 8.1 |

The specific enthalpy and entropy obtained through the property tables are:

- At $P_1$ and $T_1$.
  - $h_1$ = 3091.95 kJ/kg and s1 = 6.58 kJ/kg K
- At $P_2$ and $h_2 = h_1$
  - $T_2$ = 319 ºC
  - $S_2$ = 7.30 kJ/kg K

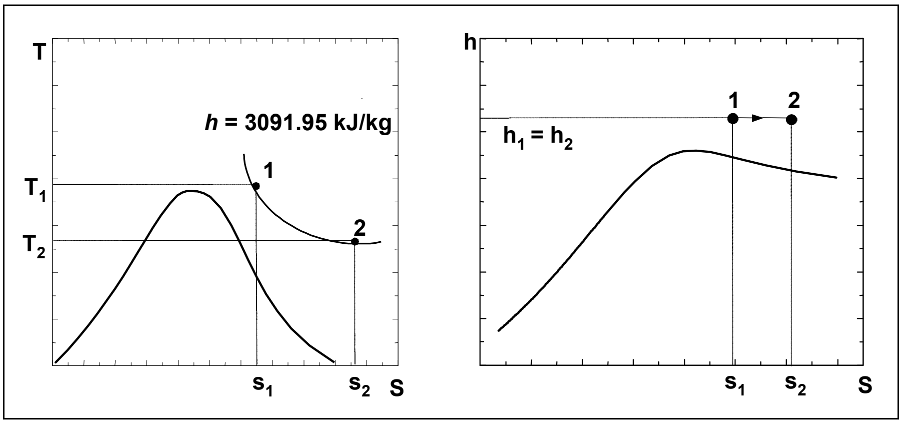

**Figure 8.2: T-s and h-s diagrams for the steam throttling process of the example**

The specific flow exergy is calculated as:

| | |
|---|---|
| $e = h - T_0 s$ | Equation 8.2 |

Where $T_0$ = 273 K and the potential and kinetic energy are considered negligible. Hence:

$e_1 = 3091.95 - 273 \times 6.58 = 1295.61$ kJ/kg

and

$e_2 = 3091.95 - 273 \times 7.30 = 1099.05$ kJ/kg

This process is completely irreversible (mechanical irreversibility). The exergy loss is obtained through an exergy balance to the system. Since there is no heat or work transfer, the exergy balance reduces to:

$$I = m\ (e_1 - e_2) = 45000\ kg/h \times \frac{1}{3600}\ s/h \times (1295.61 - 1099.05) = 2457\ kW = 2.457\ MW$$

## Case 2. Heat exchangers

Heat exchangers are devices where two streams exchange heat. Every heat transfer is the result of a temperature difference and thus is always associated with entropy generation and exergy destruction. Therefore, there is a contradiction between the ideas of minimum exergy loss and maximum heat transfer efficiency.

In a counterflow heat exchanger like the one shown in Figure 8.3, where a hot fluid at $T_{1,in}$ is cooled down to $T_{1,out}$, by releasing heat to a cold fluid that heats up from $T_{2,in}$ to $T_{2,out}$, therefore, the exergy loss in the process is calculated as follows:

The change in kinetic and potential energy are usually negligible and no work interactions are present. For a first approximation, the pressure drop can also be considered negligible. The irreversibility created in the heat exchanger is given by:

$I = (e_{1,in} + e_{2,in}) - (e_{1,out} + e_{2,out}) = (h_{1,in} + h_{2,in}) - (h_{1,out} + h_{2,out})$

$$- T\ [(s_{1,in} + s_{2,in}) - (s_{1,out} + s_{2,out})] = T_0\ [\ m_1 Cp_1 \ln \frac{T_{1,out}}{T_{1,in}} + m_2 Cp_2 \ln \frac{T_{2,out}}{T_{2,in}} \qquad \text{Equation 8.3}$$

It can be demonstrated from the equation above that I is always positive and increases with the temperature differences at the inlet and outlet of the fluids in the counterflow exchanger and between the top and bottom in a parallel-flow one. In any case, a counterflow exchanger is always better than a concurrent one (parallel-flow) from the exergy point of view, because exergy is always being giving off to a system at a similar temperature.

The irreversibilities taking place in heat exchangers are due to two factors: heat transfer caused by the temperature difference and pressure loss associated with the fluid circulation. Both fluid friction and irreversible heat transfer can be reduced decreasing the fluid flow. However, in order to obtain the same effect of heat exchange, a larger transfer area is required, i.e. larger heat exchangers must be designed.

The idea of extending the use of counterflow heat exchange to the whole installation, i.e. extending it to all flows to be heated or cooled in the plant, so that the temperature change through which heat must flow is reasonably low, leads to the energy integration of processes and the use of energy cascades. This is the philosophy of the pinch methodology, developed for the integration of heat exchanger networks. The integration can also be extended to power cycles, heat pumps and refrigeration cycles in the most efficient way. In summary, this procedure assures the lowest steam consumption (or any another heat source) and the lowest cooling water (or any other cold source) under the thermodynamic and technical conditions that may be assessed.

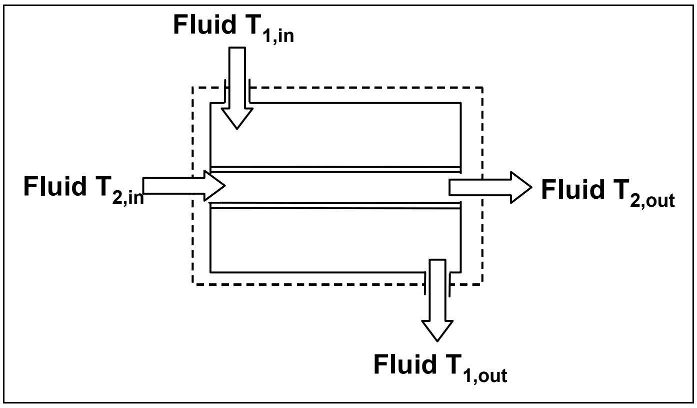

**Figure 8.3: Counterflow heat exchanger**

## Numerical example

In a boiler reheater (see Figure 8.4), 1 100 000 kg/h of steam is heated from 350 to 540 ºC at a pressure of 40 kg/cm$^2$. The heat absorbed by the steam comes from the exhaust gases of a combustion process. The average temperature where the heat transfer occurs is 1000 ºC. In Figure 8.5 the process is sketched on the T-s and h-s diagrams and the heat absorbed by the steam and exergy losses is determined.

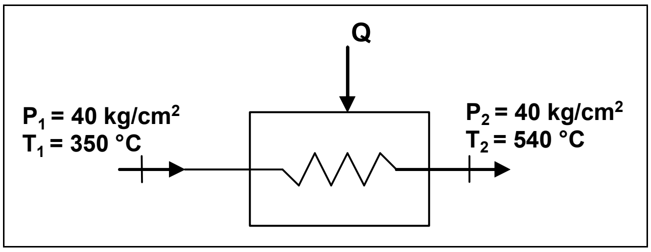

**Figure 8.4: Reheating process of a steam flow**

## Solution

The energy balance of the system considered in Figure 8.4 is:

$m (h_2 – h_1) = Q$

The specific enthalpy and entropy obtained through the property tables is:

- At $P_1$ and $T_1$.
  - $h_1$ = 3091.95 kJ/kg and
  - $s_1$ = 6.58 kJ/kg K
- At $P_2$ and $T_2$
  - $h_2$ = 3530.85 kJ/kg and
  - $s_2$ = 7.21 kJ/kg K

Hence, the heat transfer obtained is:

$Q = 11\ 100\ 000 \times (3530.85 – 3091.95) = 438.9$ kJ/kg $= 482.7 \times 10^6$ kJ/h

T-s and h-s diagrams are shown in Figure 8.5:

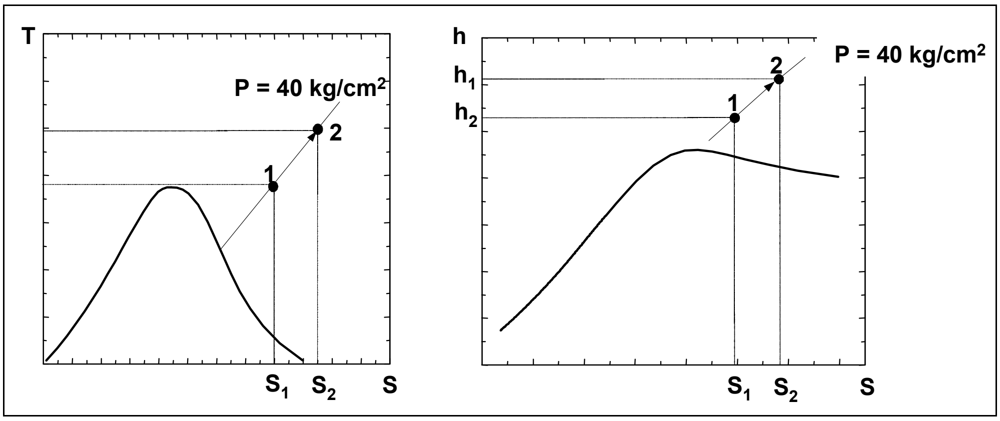

**Figure 8.5: T-s and h-s diagram for the steam reheating process of the example**

The specific flow exergy is calculated as:

$e = h - T_0 s$

Where $T_0 = 273$ K and the potential and kinetic energy are considered negligible. Hence:

$e_1 = 3091.95 - 273 \times 6.58 = 1295.61$ kJ/kg

and

$e_2 = 3530.85 - 273 \times 7.21 = 1562.52$ kJ/kg

The exergy loss generated is given by:

$$I = \left(1 - \frac{T_0}{T_j}\right)\dot{Q} - \dot{W} + \dot{m}(e_1 - e_2) \Rightarrow$$

$$I = \left(1 - \frac{273}{1273}\right) 482.7 \times 10^6 + 1.1 \times 10^6 (1295.61 - 1562.52) = 85.82 \times 10^6 \text{ kJ/h} = 23.84 \text{ MW}$$

## Case 3. Mixing processes

The mixing of fluids with different compositions or temperatures is another process very common in industry. This concept includes tempering processes for temperature control, mixing processes for quality control, substance purifying processes, distillation, etc.

For example, an adiabatic mixture of two different ideal gases flows at the same temperature and pressure and $n_1$ and $n_2$ equals the number of moles of each flow. The generation of entropy in the mixing process corresponds to the sum of the entropy increase of each gas due to their expansions from P to their new partial pressure of the mixture. Hence:

| | | |
|---|---|---|
| $\sigma = \frac{1}{\dot{n}_1 + \dot{n}_2}\left[\dot{n}_1 R \ln \frac{P_1}{P} - \dot{n}_2 R \ln \frac{P_2}{P}\right] = -R \sum x_i \ln x_i$ | (J/K) | |

Since $P_i = x_iP_i$ and $x_i = \frac{n_i}{\sum n_i}$ the exergy loss is calculated as follows:

$$I = T_0\sigma = -RT_0\sum x_i \ln x_i \qquad \text{(J)}$$

This expression is always positive and symmetrical with respect to the value $x_i = 0.5$. It tends to zero when $x_i$ tends to zero (maximum purity). Figure 8.6 shows $I_i/RT_0$ versus the molar fraction of one component in the mixture $x_i$. The maximum exergy is reached when $x_i = 0$, but under these conditions, it is relatively easy to separate both components. As the mixture is being purified, the exergy loss per mol of the separated component increases.

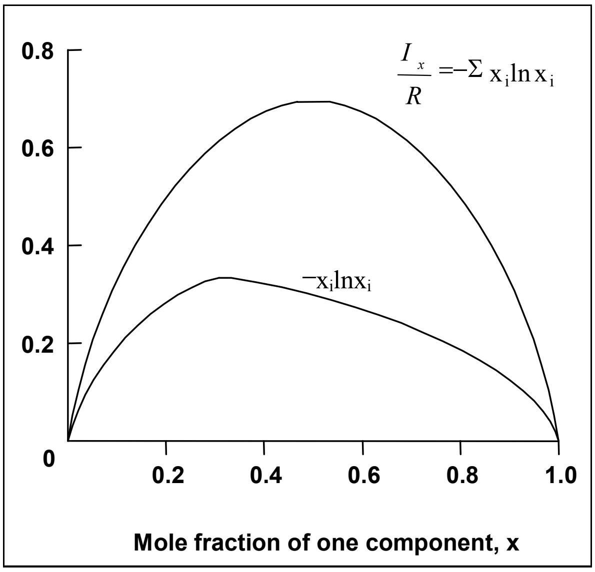

**Figure 8.6: $I_i/RT_0$ versus molar fraction of one component in the mixture**

For the considered binary system, the irreversibility is equal to:

$$I = -RT_0\left[x\ln x + (1-x)\ln(1-x)\right] \text{ and } \frac{dI}{dx} = -RT_0 \ln\left[\frac{x}{(1-x)}\right]$$

Some of the values of this derivative are presented in Table 8.1:

| x | I/RT0 | (1/RT0) dI/dx |
|---|---|---|
| 0.10 | 0.325 | 2.20 |
| 0.01 | 0.056 | 4.96 |
| 10 - 3 | 7.91 x 10 - 3 | 6.91 |
| 10 - 4 | 1.02 x 10 - 3 | 9.21 |

**Table 8.1: Some values of the derivatives**

This derivative indicates the work required to improve the purity of the product and the easiness to pollute. In other words, the exergy value of the product is related with this derivative. Multicomponent mixtures behave in the same way. The maximum value of the function $-\sum x_i \ln x_i$ that takes place for equimolar mixtures is shown in Table 8.2:

| N | $-\sum x_i \ln x_i$ | N | $-\sum x_i \ln x_i$ |
|---|---|---|---|
| 2 | 0.693 | 5 | 1.609 |
| 3 | 1.099 | 7 | 1.946 |
| 4 | 1.386 | 10 | 2.302 |

**Table 8.2: Maximum values for mistures**

As the number of components of the mixture increases, the irreversibility effects become more dramatic. These ideas lead to a set of recommendations for energy saving in mixing processes. Firstly and most importantly, mixing processes must be avoided whenever it is possible. Obtaining high quality steam or a very pure substance requires a great amount of exergy that is mostly lost when mixed with a lower quality flow (even if the energy loss is zero). Secondly, the quality specifications of a certain product must not be exceeded and above all, once they are exceeded, they should never be mixed with lower quality flows.

This way, if a product with 0.1 % purity is mixed equimolarly with another of 1 % purity, the final product will have 0.55 % purity, but the exergy value of this product will decrease significantly with respect to the individual flows, since this is related with the derivative $\frac{dI}{dx}$ and not with the mean composition value.

Some quality specifications of products should be reviewed and should be made ‘softer’ if possible. This is something basic in the chemical industry, in which it is very common to find partially refined matter mixed with over purified products or mixtures of products coming from two parallel units for achieving an average purity.

### Numerical example

A steam flow at a pressure of 180 kg/cm$^2$ and a temperature of 550ºC is mixed with saturated liquid at 180 kg/cm$^2$, in order to reach the temperature design specifications of a certain equipment (see Figure 8.7).

In Figure 8.8 the final temperature of the mixture and the exergy loss is determined when the mass flow of steam is 1 100 000 kg/h and of the liquid 30 000 kg/h.

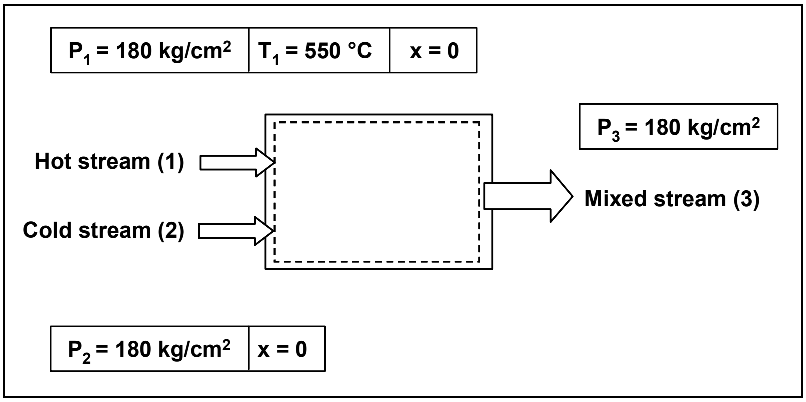

**Figure 8.7: Mixing chamber of two flows**

**Solution**

The mass balance of the system is:

$m_l + m_2 = m_3$

Since there is no work or heat transfer to the process and the kinetic and potential energy can be assumed to be zero, the energy balance reduces to:

$m_l h_l + m_2 h_2 = (m_2 + m_l) h_3$

At $P_l$ and $T_l$, the specific enthalpy and entropy obtained through the property tables is: $h_l = 3414.2$ kJ/kg and $s_l = 6.41$ kJ/kg K respectively. For the saturated liquid at the cold stream (2), only one property (pressure in this case) is needed to fix the state: $h_2 = 1717.06$ kJ/kg and $s_2 = 3.85$ kJ/kg K. From the energy balance applied above:

$$h_3 = \frac{1.1\,x10^6(3414.2) + 30\,x10^3(1717.06)}{1.13x10^6} = 3369.14\ \mathrm{kJ/kg}$$

At the mixed stream (3), with $h_3$ and $P_3$, $T_3 = 534$ ºC and $s_3 = 6.35$ kJ/kg K.
The change in specific enthalpy and entropy can be obtained with the help of the property tables in . The specific flow exergy is calculated, where $T_0 = 273$ K and the potential and kinetic energy are considered negligible. Hence:

| | | | |
|---|---|---|---|
| $e_l = 1664.52$ kJ/kg, | $e_2 = 666.67$ kJ/kg | and | $e_3 = 1634.55$ kJ/kg |

The irreversibility is obtained through the exergy balance:

$I = m_l(e_l - e_3) + m_2 (e_2 – e_3) =>$
$I = 1.1 \text{ x } 10^6(1664.52 – 1634.55) + 30 \text{ x } 10^3(666.67 – 1634.55) = 3.76 \text{ x } 10^6$ kJ/h = 1.04 MW

The T-s diagram is shown in Figure 8.8:

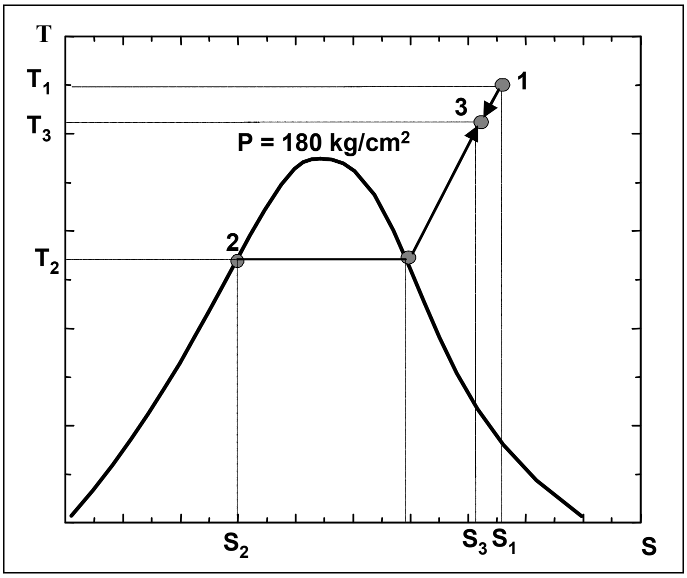

**Figure 8.8: T-s diagram for the mixing process of the example**

**Remarks for all three case studies**
Irreversibilities are the effects of any improvable energy system. Besides avoiding finite pressure, temperature and/or chemical potential differences, the causes of poor energy design come from decoupling supply and demand. Time plays an important role in energy efficient systems. Energy systems spontaneously decrease its pressure, temperature and chemical potential to reach equilibrium with its surroundings. To avoid this there are two strategies:

- to couple energy donors with energy acceptors immediately
- storage: to enclose a system within rigid walls for pressure; adiabatic walls for temperature, and/or to confine the chemical systems into metastable states.

In other words, confine the systems into reservoirs that maintain their intensive properties constant with time.

# ANNEX 2 EXAMPLE OF APPLICATION OF ENERGY EFFICIENCY

## Mineral oil refineries

The refineries already take seriously into account energy efficiency issues because energy costs represent more than 50 % of global operating costs. On a single refinery level, energy efficiency can be followed by the energy intensity factor. In fact, it is simpler to use the ratio between globally consumed energy on the site to the amount of treated crude, which is equivalent to the EIF. Following this ratio against time requires interpretation, in order to clarify what comes from energy management and what comes from other factors. However, this ratio cannot be used for the purpose of comparing the energetic performance of different refineries, as all refineries are different in complexities, schemes, processed crudes and production mixes. All these parameters affect the energy needs of the refineries.

An attempt to catch this complexity is the Solomon Energy Benchmark for refineries. For refineries, Solomon associates have introduced the concept of the energy intensity index (EII). Solomon associates carry out a worldwide benchmark study of refineries every two years. It covers all aspects such as capacity, maintenance costs, operational expenditure, and also energy efficiency. The energy efficiency is measured via the EII indicator, which is defined as follows *(note: this equates to specific energy consumption, SEC, in Section 1.3.2)*:

$$\text{EII} = 100 \times \frac{\text{Total actual refinery energy consumed}}{\Sigma(\text{Unit utilised capacity x Unit energy standard}) + \text{Sensible heat} + \text{Offsite energy}}$$

In this equation:

- the numerator is the total actual refinery energy consumption (expressed in lower heating value) and equals the total consumption of fuel/electricity (both import and internal generation), but also takes into account any export of steam and/or electricity. Electricity from the external grid is converted to primary energy using a standard efficiency factor of 37.5 %.
- the denominator is the standard energy consumption according to Solomon (called guide energy) and consists of three main elements:
    - the sum of the guide energies for each of the production units: this guide energies are calculated by multiplying the unit utilised capacity (normal throughput or feed rate) with a unit specific energy standard factor provided by Solomon for each unit. For some production units, this energy factor depends on feed quality (e.g. crude density)/operation severity (catalytic reformers, catalytic crackers, etc.)/type of production facility, etc. These guide energies per unit are summed to give the total standard energy consumption for all of the refineries production facilities according to Solomon
    - a sensible heat factor: this factor accounts for the energy required to raise the plant input from ambient temperature to 104.4 C. The basis for the plant input is all gross raw material input streams (and their respective densities) that are ‘processed’ in process units. Blend stocks are not taken into account
    - an offsite energy factor: this factor accounts for the energy consumed in utility distribution systems and operation of product blending, tank farms (tank heating, heating of rundown lines, terminalling facilities) and environmental facilities. The basis for the calculation is the raw material input to process units as well as to blending operations and a complexity factor of the refinery.

The EII is dimensionless and, in contrast to the definition of EEI presented in Section , decreases with increasing energy efficiency.

The EII attempts to compare the energy efficiencies of refineries having different complexities and different units. Still this tool is considered by the refining industry as an imperfect tool for comparison purposes at best. Some refineries that have a poor EII have few opportunities for improving energy efficiency, whereas others with a good EII sometimes still have a large potential for improvement. Moreover, the EII does not give a good insight to the areas/units that need improvement. The detailed breakdown of the site into main production units can be of more help in this respect to identify opportunities for improving energy efficiency.

## Ethylene cracker

Ethylene crackers convert feedstock coming from the refinery into ethylene and propylene which form the main feedstock for the polymers industry. Ethylene crackers are highly energy intensive. Energy costs represent more than 50 % of the operational costs of a unit.

Feedstocks (Fi) typically are naphtha, LPG and gasoil coming from refineries. The main products ($P_1$) are ethylene and propylene. Within the industry however, it is the custom to add three other high value products to the main products for comparison purposes: butadiene, benzene and hydrogen. Butadiene and benzene do not in fact come out as pure products in a cracker. Butadiene is part of the $C_4$ stream and benzene of the cracker gasoline stream. They are usually extracted in dedicated extraction units which do not form part of the overall picture of the ethylene crackers.

Usually the ratio of these high value products to ethylene varies in a narrow window (between 1.7 and 2.3) and will depend on cracking conditions and feedstock quality/type.

For plants where the economics are mostly driven by ethylene production, a more meaningful energy indicator might be to divide energy use by ethylene production rather than by high value chemicals.

**Energy vectors**

- steam: a typical ethylene cracker would usually have several steam levels (a high pressure level of approx. 100 barg, a medium pressure level of approx. 20 barg and low pressure level of approx. 4 barg). Depending on the configuration, the cracker will import steam at some levels and export at other levels
- electricity: most crackers are net electricity consumers. Those equipped with cogeneration may be net exporters of electricity. Within the industry, the convention is to use a conversion factor of 37.5 % to convert electricity to primary energy when comparing different plants
- hot water: most crackers produce relatively large amounts of hot water. However, in most cases, the temperature of this hot water is too low for use by other plants but, in some cases, integration with other plants or outside consumers is possible. In this case a credit should be given for export of these calories. So, an improvement of energy efficiency is determined by an 'external' circumstance, independent of the 'intrinsic' performance characteristics of the unit under examination that is the actual possibility of using an output stream for a duty that otherwise should be satisfied with additional primary energy. As a consequence, two units with the same 'intrinsic' performance' would be rated differently if only one of them can find an energy use for one of its output streams (heat integration)
- fuel: most crackers produce a liquid fuel (pyrolysis fuel oil) and gaseous fuel (a methane rich mixture). Most of the gaseous fuel is recycled to fire the ethylene furnaces. Depending on the configuration and mode of operation, the gaseous fuel produced may be self sufficient to fire all the furnaces and the rest of fuel gas is exported, or there may still be a deficit so the import of an external fuel is required which is typically natural gas. Only the fuel consumed internally by the ethylene cracker is taken into account in the energy balance. All fuels exported are counted as products (this is logic as the fuel value was already present in the feedstock)
- cooling water: all crackers use cooling water. Sometimes cooling towers are part of the ethylene cracker, however, this cooling water comes from cooling towers which also supply cooling water to other production units. In this case, the energy related to the production of cooling water is often not reported when calculating the energy efficiency of the process
- ethylene processes also use other utilities such as $N_2$ and compressed air. Often these utilities are produced centrally on the site or by a third party. The energy related to these utilities is often not counted.

# VAM production

Some of the components of the proposed Section to calculate the energy intensity factor (EIF) may not be applicable for each process. Therefore it has to be modified to the prevailing needs.

As an example, a vinyl acetate monomer (VAM) plant is taken. Several components of a VAM plant are not being measured or quantified (here marked with (?)) whereas others can easily be named (here marked with (✓)), see Figure 8.9.

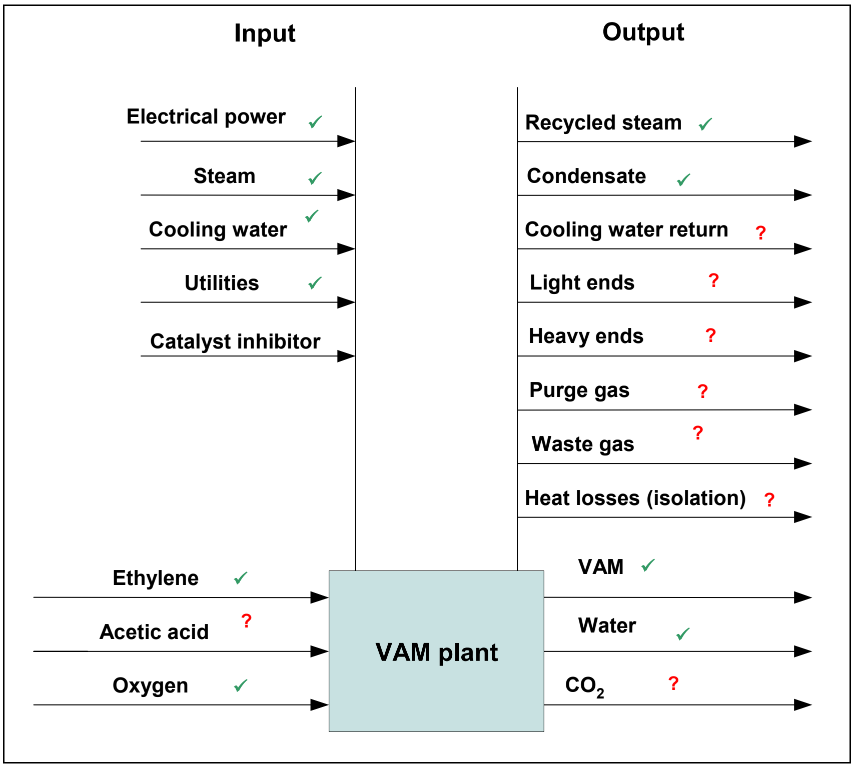

**Figure 8.9: Inputs and outputs for a vinyl acetate monomer (VAM) plant**

As stated in Section , heat losses via cooling water return and isolation should never be counted in the EIF or EEI. Waste gas and purge gas should not be counted if it is incinerated without heat recovery. For those terms it may however be useful to gain some insight into their order of magnitude to verify the economic potential needed to reduce these losses or waste streams.

In contrast, more reflection is required on the other terms such as light and heavy ends or if waste and/or purge gas are valorised in other processes. In the proposed , these streams were not included as it is assumed that the fuel content of these streams is already present in the feedstock. However, it is the responsibility of the operator to define how to account for these terms.

## A hot rolling mill in a steel works

The feeding to a rolling mill consists of approximately 2 decimetres thick, flat steel plates that are to be rolled out to bands with a thickness of a few millimetres. The rolling mill consists of furnaces, rolling mill equipment, cooling equipment and support systems including pumps, fans, hydraulics and lubricating systems, lights, a mechanical workshop, staff space, changing rooms etc.

A flow chart of a rolling mill is shown in Figure 8.10.

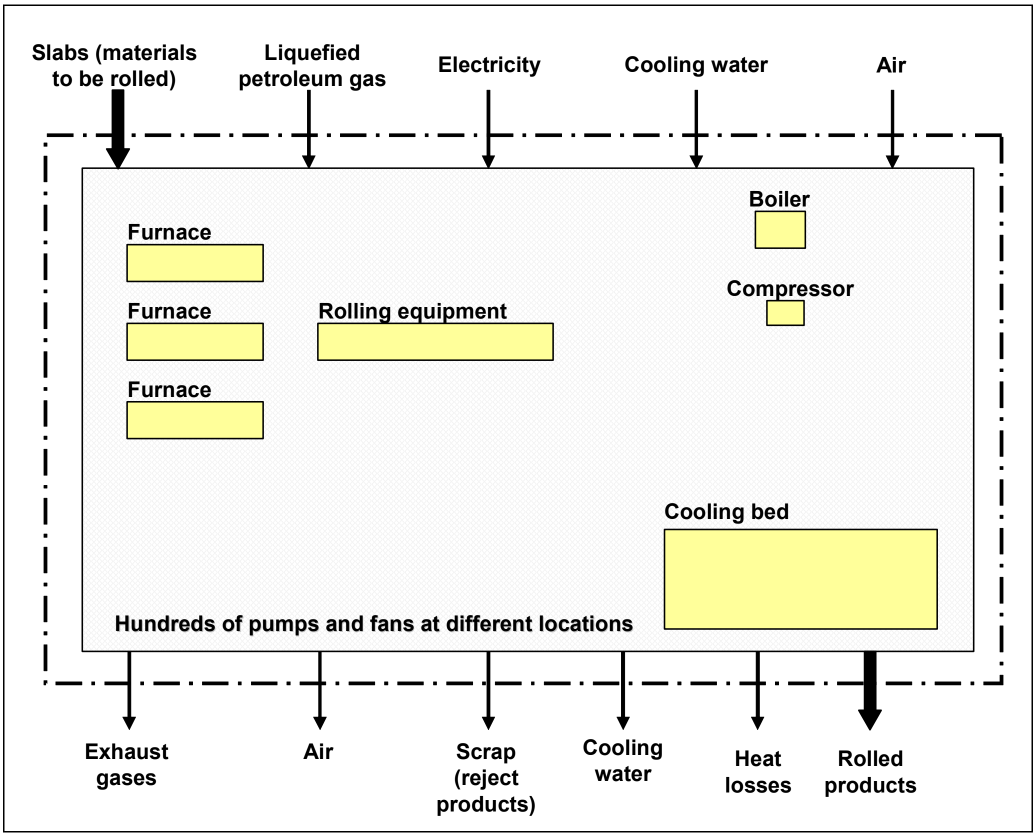

**Figure 8.10: Flow chart of a rolling mill**

In this case, several different primary energy sources are involved. However, the following discussion is restricted to the use of electric energy. The number of electrically driven components or subsystems in a rolling mill can be estimated at more than one thousand.

The electric energy consumption can be registered easily with reliable electricity meters. The steel production may either mean the weight of slabs entering the rolling mill or the weight of rolled and approved final products. The difference corresponds to the weight of scraps that may fall at different stages in the rolling mill.

An analysis of data taken from an existing rolling mill during a period of 11 weeks was made and some of the results are shown in Figure 2.14. The energy consumption varied between around 120 and 80 kWh per tonne delivered products, dependent on how many tonnes that were produced per week. The average consumption was thus 100 kWh/tonne and the variation ± 20 %. No energy saving measures were taken during this period.

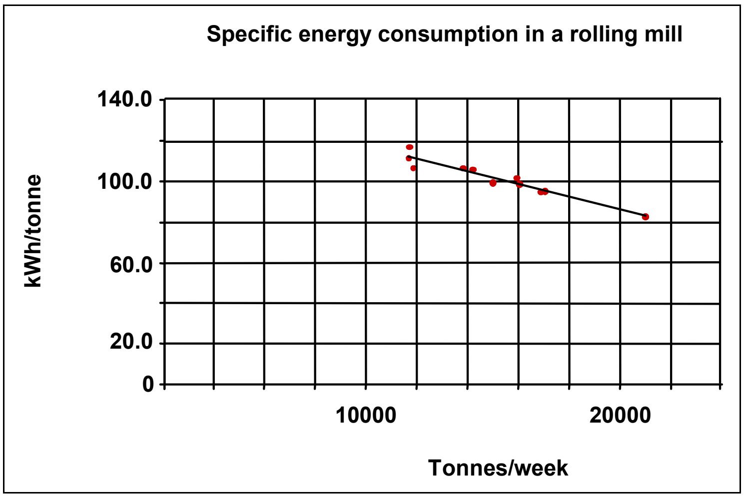

Figure 8.11: Specific energy consumption in a rolling mill

The reduction of the specific energy consumption with an increasing production rate is quite normal and is caused by two factors:

- the production equipment will be operating for longer periods when the production rate is high. This means that the idling periods become shorter. Some types of equipment are running continuously, even during non-production time. This type of energy consumption will be reduced when the non-production time gets shorter
- there is a base energy consumption that does not depend on the utilisation of production capacity. This consumption is related to the use of lighting, fans for ventilation, office machines, etc. At higher production rates, the consumption will be spread over more tonnes of products.

The decrease in the specific energy consumption with increasing production rate is thus caused by fluctuations in market conditions which are beyond the company's control.

A programme to improve energy efficiency was then carried out at the rolling mill. A number of measures were taken with the aim of decreasing the energy consumption and the results of these measures are illustrated in Figure 2.14. The results appeared to be largely independent of the production rate. As can be seen in Figure 2.14, it is possible to separate the results of energy saving efforts and results caused by other factors, such as the utilisation of capacity.

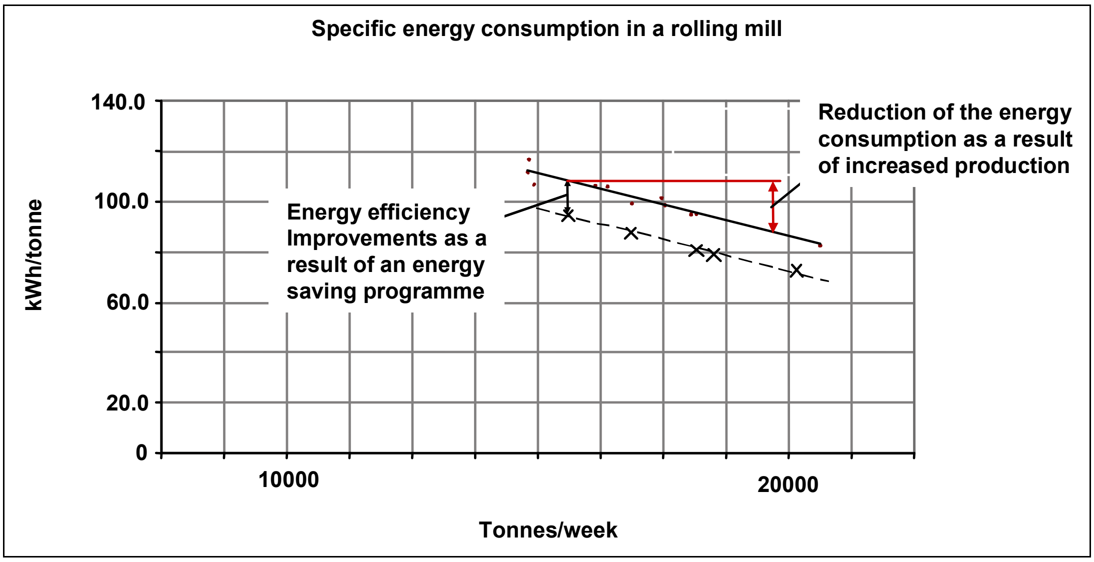

Figure 8.12: Changes in specific energy consumption in a rolling mill

It is also obvious that interpretation difficulties will arise when comparing the specific energy consumption month by month or year by year. The specific energy consumption may very well increase from one period to the next though a number of energy saving measures have been taken. In this case, the effect of such measures is not large enough to compensate for the increase in energy consumption due to low production rates.

# ANNEX 3 EXAMPLES OF IMPLEMENTATION OF ENERGY EFFICIENCY MANAGEMENT SYSTEMS

**Example 1: Aughinish Alumina (AAL), Ireland** [161, SEI, 2006]
Aughinish Alumina (AAL) is Europe's largest alumina refinery, producing more than 1.6 million tonnes of alumina yearly by treating bauxite ore, which is then exported to smelters for processing into aluminium. The plant, located on the island of Aughinish, Co Limerick, is one of Ireland's largest energy users and employs 400 staff. Alumina refining is an energy intensive process, with energy accounting for about 30 % of the total cost.

The company responded to a suggestion by SEI to implement an E2MS. The system chosen was the Danish DS 2403 (the Irish IS 393 is based on this, and has subsequently been issued). The company chose a standardised system to guarantee delivery of a systematic and structured approach to improving energy and reducing energy-related costs. DS 2403 is very similar to ISO 14001, and this was of major benefit, as it required little more than shaping the E2MS to fit with the existing 14001 procedures.

Danish consultants carried out a preliminary review and audit, and a gap analysis of what was needed to meet the standard. A full time energy manager was appointed to develop the necessary systems. AAL already had extensive metering in place so the emphasis was on making better use of available data and instigating formal reviews and reporting procedures to highlight problems and identify opportunities.

All engineers, maintenance, and purchasing personnel whose work was directly affected by the requirements of the Standard were given a one-day training course on its operation. The remaining 400 employees were given a one-hour 'Energy Awareness' presentation covering more general points

*Examples of actions identified and undertaken:*

1. Improved heat recovery
A series of shell and tube heaters use regenerative steam to heat boiler feed-water to 120°C before it enters the deaerators. The performance of the heaters was poor for some time, due to scaling in the steam lines. This led to non-conformances, which in turn initiated a more focused programme of troubleshooting to identify how best to resolve the problem. Thermographic analysis and pressure surveys identified possible regions of high pressure drop in steam lines. This information, coupled with detailed calculations to identify what pressure drops were tolerable, indicated that AAL should make specific modifications in one area at the annual plant shutdown. The analysis proved correct and the modifications resulted in a significant improvement in energy efficiency. The approach was successfully applied in another location and further improvements are expected when other areas are modified later in 2006.

2. Higher feed temperature for input stream
Lime slurry must be added to the digester to control extraction. The slurry temperature must be as high as possible; otherwise the digester will require more steam from the boilers to achieve its target temperature. Operating problems early in 2005 resulted in low slurry temperatures and non-conformances. The resulting investigation identified a simple, low cost method of resolving the problem; it is unlikely that this would have happened without the Standard. Although the saving was small in the context of AAL's overall energy bill, it was nonetheless real and also improved operation of the lime slaker.

**Example 2: Outokumpu, Tornio works,** Finland [160, Aguado, 2007]
Outokumpu is an international company and Tornio works is the world's largest integrated site producing stainless steel, with a capacity of 1.65 M tonnes and employing 2300 staff. They are integrating their energy efficiency management with their ISO 14001 EMS, and energy consumption reporting within this will be instigated at the site before 1 Dec 2007. They were listed in the Dow Jones Sustainability Index in 2006, which charts corporate responsibility.

Other sites: Avesta, Degerfors and Nyby successfully certified their Energy Efficiency MS systems to SS 627750 in 2006. Avesta has a Dec 2007 target to reduce electricity consumption by 3 % from 980 to 950 kWh/tonne, and fuel efficiency (LPG) by 2 % from 608 to 596 kWh/tonne. Degerfors has the objective to reduce energy use for heating in the dispatching area by 40 % from 2005. Sheffield (melting shop) is to introduce an energy management system, with an energy group and energy champion, and aims to reduce non-production energy use by 10 %, against 2006 usage (again, by Dec 2007).

**Example 3: The Dow Chemical Company** [163, Dow, 2005]
The Dow Chemical Company is an international company with six operating segments, 28 businesses and more than 3200 products with annual sales of USD 40 000 million. They employ 43 000 staff on 208 manufacturing sites in 38 countries worldwide. Their power consumption is 3500 MW, of which 54 % is generated internally and 74 % of this is co-generation.

Dow uses the management systems, work process and continuous improvement tools that are already in place.

Goals set by Global Management Board: 1995 – 2005, improvement in energy efficiency 2 % per year (20 % total with 1994 as reference year). 2005 – 2015 goals were being set in 2005.
Strategy: to ensure long term sustainability, business units include energy efficiency and conservation goals and plans as part of their strategic planning and project implementation.

Dow's implementation of energy efficiency addresses all the requirements as set out in Section 2.1 such as a defined structure, communication, data management, identification of opportunities and implementation. Energy efficiency is part of 'Most Effective Technology' development and appropriately evaluated in long term investments. Marketing, brainstorming and leveraging are also used. There is a Global Energy Conservation Leader, supporting all the businesses in Dow. Each location has an energy efficiency focal point/leader to co-ordinate the energy efficiency activities in that location, with Energy Conservation Steering teams at major hub locations.

Staff are engaged by publicised success stories, energy efficiency tools everyone can use, external links, savings contests, and other activities.

The structure is integrated, site energy steering teams comprised site and plant leadership, and an 'Across the Business Envelope' approach. This ensures process plant objectives really translate into actual savings at a company level, maximises integration and energy use synergies between plants, sharing and leveraging of ideas and projects, as well as identify opportunities at site level and planning.

A key factor is the use of existing work processes and continuous improvement tools with:

- a focus on engineering/most effective technology - energy efficient solutions
- A focus on maintenance/operations /energy Teams
- inclusion of by-product fuels/alternative energy and improvements in Energy Intensity reporting (the use of by-product fuel might have a negative effect on overall fuel efficiency, but could reduce $CO_2$ emission by other fossil fuels, therefore should not be penalised as a negative effect on energy efficiency)
- six sigma implementation: this is a data driven methodology to 'reduce re-work' and 'Sustain the Gains', and involves systematic 'measure-analyse-improve-control'. It uses (among others) customer requirement evaluation, statistical analyses and opportunity prioritisation tools. Improvement implementation focuses on change management, management commitment and communication.

*Achievements*
Dow achieved the targeted 20 % reduction in specific energy consumption (referred to as energy intensity by Dow and other chemical and petrochemical companies), down from 13 849 kJ/kg of product to 11 079 kJ/kg, measured as kg of total DOW product mix.

*Examples of specific improvements*

Dow Central Germany (five locations):
- Optimisation of the Boehlen location steam and fuel gas balance resulted in a considerable annual $CO_2$ reduction, and (local) energy efficiency improvement
- A hydrogen envelope improvement project was initiated between two locations (40 km apart) to minimise the vented/flared hydrogen and maximise chemical and fuel usage which resulted in a closed hydrogen balance (minimised losses) and $CO_2$ reduction measures.

Freeport site, Texas, US:
- Initiation of a site wide programme to reduce electrical consumption on motor driven systems. A tool was developed to allow operations personnel to assess energy savings opportunities and to either develop operating procedures to reduce energy use or to identify opportunities for engineering changes.

Terneuzen site, NL:
- Optimisation of the steam balances between power and utilities and the olefins cracker production facilities resulted in less steam losses and more efficient steam reduction (turbine/reduction stations).

# ANNEX 4 EXAMPLE OF ENERGY EFFICIENT CORE PROCESSES

## Example 1: The enzymatic production of acrylamide (Mitsubishi Rayon, Japan)

[164, OECD, 2001]
In the classic process, acrylonitrile was hydrolysed by the addition of stoichiometric amounts of sulphuric acid in the presence of polymerisation inhibitors to prevent both starting materials and products polymerising. In the 1970s, a heterogeneous copper catalyst was developed which eliminated the need for sulphuric acid. It had many advantages and was widely applied.

However, the development in polymerisation technologies and polymer applications created a new demand for more highly purified acrylamide monomer. This revealed that the acrylamide produced by the catalytic process, which had been recognised as high quality, nevertheless contained minor by-products that affected the polymerisation reactions. MRC therefore started development of an enzymatic acrylamide production process which reduced the level of by-products. This was hydrolysis using a recoverable immobilised whole cell catalyst.

Pilot scale development of the first-generation microbe took one and a half years for process development and quality assurance. For the second and third generations, about 6 months of bench-scale test were sufficient to ensure the process application and product quality. The development of the GMO took about 7 years to build up the relevant technologies.

| | **Worldwide acrylamide production capacity $10^5$ tonnes/year** | | | |
|---|---|---|---|---|
| **Process** | **Japan** | **Asia (excl. Japan)** | **United States** | **Europe** |
| Catalytic | 0.9 | 0.75 | 1.35 | 1.15 |
| Enzymatic (1998) | 0.2 | 0.2 | 0.1 | 0.35 |
| Enzymatic (2001, est.) | n.a. | 0.5 | n.a. | 0.45 |

**Table 8.3: Worldwide acrylamide production capacity 105 tonnes/year**
**[164, OECD, 2001]**

The first enzymatic process required decolourisation and concentration steps, but the new process did not, see Table 8.4

| **Reaction process** | **Catalytic (1971-)** | **Enzymatic (1985-)** |
|---|---|---|
| Reaction temperature | 343°K | 273 - 288°K |
| One-pass reaction yield | 70 - 80 % | ~ 100 % |
| Acrylamide concentration | ~ 30 % | 48 - 50 % |
| Concentration | Required | Not required |
| Purification | Catalyst removal | Protein removal |

**Table 8.4 Comparison of acrylamide processes**
**[164, OECD, 2001]**

Comparative studies have been carried out on the environmental impacts of the catalytic, the original enzymatic and the new enzymatic processes. The conclusions are that the biotechnological approach has lower impacts than the catalytic process, particularly for energy consumption and carbon dioxide production. The energy savings are given in table Table 8.5 and Table 8.6.

| | **Catalytic** | **Enzymatic (old process)** | **Enzymatic (new process)** |
|---|---|---|---|
| Steam | 1.6 | 2.8 | 0.3 |
| Electric power | 0.3 | 0.5 | 0.1 |
| Raw materials | 3.1 | 3.1 | 3.1 |

**Table 8.5 Comparison of energy consumption as MJ/kg acrylamide**
**[164, OECD, 2001]**

| | Catalytic | Enzymatic (old) | Enzymatic (new) |
|---|---|---|---|
| Steam | 1.25 | 2.0 | 0.2 |
| Electric power | 0.25 | 0.25 | 0.1 |
| Raw materials | 2.3 | 2.3 | 2.3 |

**Table 8.6: Comparison of $CO_2$ production Kg $CO_2$/kg acrylamide**
**[164, OECD, 2001]**

### Example 2: Use of radiation cured inks or paint systems in place of conventional solvent based systems

54" heat set press (≈ 1.37 m). The typical print job is 35 - 40 % coverage on a light 12-point board stock. The calculations are based on three shifts, 75 % available hours running = 4680 hours per year.

*Conventional inks and drying system:*
Solvent based inks and coatings, 60 – 65 % solids. The driers use gas to heat air to approx. 150°C. The electricity to move the air is included in the calculation.

Often, the substrate is cooled over chill rollers after the ovens. The solvent-laden air (waste gas) is usually treated (by oxidisers). The energy requirements for these two systems have not been included in the calculation.

*Electron beam (EB) system:*
EB inks are 100 % solids. When exposed to high-energy electrons they polymerise or cure (melt and then harden). Minimal heat is deposited into the substrate (temperature shift about 8 – 12°C so no cooling is required. There are no waste gases containing solvent to treat. However, the EB curing requires an inert nitrogen atmosphere. No data for the energy used to generate was given, so the cost per unit volume of $N_2$ has been assumed to be entirely electrical energy used in its generation, and this has been added to the energy usage.

| GJ per year | Conventional | EB |
|---|---|---|
| **Gas** | $4.67 \times 10^4$ | - |
| **Electric** | 384 | $5.31 \times 10^3$ |
| | $4.7 \times 10^4$ | $5.31 \times 10e^3$ |
| | | |
| **Savings** | | 41 690 GJ/y |
| | | 89 % |
| **Cost savings** | | USD 649 162<br>(2006, on combined NG and electricity cost) |

**Table 8.7: Energy savings; electron beam ink system**
[175, Saunders_R., 2006]

### Example 3. Heat recovery in broiler housing (intensive chicken farming)

Normally, the air in a broiler house is heated. In the 'combideck' system, the floor is heated. The system consists of a heat pump, underground storage comprising tubes, and a layer of isolated hollow strips below the floor. Broilers require heat until about day 21 (about 28°C), which is supplied by pumping hot water through the underfloor system. After a short period of equilibrium, the growing process generates excess heat. This is now absorbed into water in the underfloor system and is stored in the ground. The system has a better performance on broiler production (reduction of mortality, higher meat price, better feed ratio) and a positive effect on animal welfare (less heat stress, lower mortality, less veterinary services needed).

Investment costs are EUR 2 per broiler place with 20 broilers per m$^2$. Operational costs (depreciation, interest and maintenance) are EUR 0.20 per broiler place year. The annual increased yields reportedly outweighed the yearly operational costs by a factor of about 3. For instance, veterinarian costs were reduced by about 30 %. Energy costs were reduced by about 52 %. The payback time is about 4 – 6 years. Broiler housing: Section 4.4.1.4, [173, EIPPCB, 2003]

# ANNEX 5 EXAMPLE OF MAINTAINING THE IMPETUS OF ENERGY EFFICIENCY INITIATIVES: OPERATIONAL EXCELLENCE

**Example 1: Shell Nederland Chemie, Moerdijk, the Netherlands** (900,000 mt/year ethylene plant).
The company sought to reduce energy costs and carbon dioxide emissions. A project was implemented in partnership with Shell Global Solutions using the company's 'Energise' programme.

The plant staff were constantly searching for ways of saving energy, but had limited time, due to the need to concentrate on maintaining production continuity and product quality. There was doubt that significant savings could be made at the lower olefins plant, as it was already very energy efficient. However, Energise consultants worked with plant representatives to devise operational improvements designed to reduce energy use.

Initially, the team identified 150 opportunities for improvement, and, after review, 23 of these were developed and implemented as formal projects. Work was carried out without a shutdown and while the plant was operational. About 59 % of the total savings were obtained by modifying process control strategies, including configuring new control loops and optimising set points. The remainder of the savings came through procedural changes (23 % of the total) and by improving maintenance of process equipment and instrumentation (18 %). Key improvement areas were:

- significant savings were made by adjusting the pressure levels around the compressor systems, and installing new instruments to facilitate running the compressors at optimal performance. Control modifications for the propylene refrigerant compressors cut power demand by about 10 %, for example
- operational variation was also significantly reduced over the entire throughput range, which decreases the likelihood of capacity restrictions, and may avoid the occasional need to reduce overall plant throughput. In particular, summertime capacity bottlenecks have been significantly reduced
- many of the energy savings came from achieving a better understanding of the plant's steam balance, fine-tuning the equipment, and investing in instrumentation to monitor equipment performance.

The focus was on Operational Excellence, best practices and process control strategies, not investment in new hardware. The series of small-scale projects had a capital investment of USD 100 000 (reported in 2006: about EUR 75 000) for engineering, procurement, and construction of the additional electronic instrumentation.

Energy savings of USD 5 million/year (about EUR 3.6 million) , or 3.5 % were achieved.

**Example 2: Dow Corning, several installations.**
Operational Excellence was implemented at all plants, by improving manufacturing assets with heightened operating discipline. The plants became more reliable and operated predictably, yielding significant benefits in higher product quality and higher plant utilisation. This revealed hidden capacity in all plants of generally 15 - 20 %, with minimal capital investment.

# ANNEX 6 MONITORING AND METERING

## Quantitative measurements – metering

Two corporate divisions shared one electricity utility meter. Costs were split on a 60/40 basis, with the division paying 60 % experiencing disproportionately high energy costs. This division faced closer and relocation. An advanced metering system with automated meter reading was installed (see Section 2.7.5). This showed that the division paying 60 % was actually using <41 % of the complex's electrical energy. It also identified a heat treating process that caused a 175 kW spike once a week. This was moved to a time of day with a cheaper tariff (see Section 5.2). Total savings were USD
324 000 (≈ EUR 240 000) per year.

## Model-based utilities optimisation and management

**Example 1: Schott AG, DE**
The company produces different kind of glass products and has several production sites in Germany and elsewhere.

Energy consumption and related costs were historically allocated to various units within the company on a fixed basis, and not on actual usage. The managers could therefore not influence their energy costs, so there was little motivation to reduce consumption. The company introduced an automated energy monitoring system (ECS- energy control system), with fully electronic metering, and software modelling:

- electricity: 940 measuring points
- water: 203 measuring points
- gas: 49 measuring points
- compressed air: 43 measuring points
- fuel oil: 8 measuring points
- $N_2$, $O_2$, $NH_3$: 7 measuring points.

Achieved environmental benefits:

- energy savings by raised cost consciousness
- optimisation of energy use

Operational benefits:

- faster elimination of defects with less production losses
- smoothing of energy delivery
- transparency of energy flows.

Economics:

- software: about EUR 50 000
- hardware: about EUR 500 /measuring point
- savings per year:
    - peak load lowering at delivery of electricity: about 3 to 5 %
    - payback period: about 0.9 to 2 years (dependent on project)

Schott glass: [127, TWG]

**Example 2: Atrium Hospital, Heerleen, NL**
The hospital had built a state-of-the-art tri-generation utility in the late1990s, to produce and deliver steam, heat, electricity and cooling to the hospital 24 hours a day, with 100 % reliability. The utility comprises a hot water boiler, two steam boilers, electrical and absorption chiller units, heat exchangers, two gas engine based CHP units and two emergency generators. The complexity of the plant and utility and fuel costs made optimum economic operation impossible. A survey was carried out (see Section 2.5.2). As a result, a flue-gas condenser was installed, saving about 520 to 713 MWh per year: 5 % of energy demand. A real-time utilities management system was installed, with an internal ROI of 49 % (at about EUR 75 000 - 95 000/yr on a variable energy cost of about EUR 1.2 million. Atrium Hospital [179, Stijns, 2005]

# Energy models, databases and balances

### Example 1. Electric energy models

The contact of a simple electric model is illustrated in Table 8.8.

| | | A | B | C | D | E | F | G |
|---|---|---|---|---|---|---|---|---|
| **DEPARTMENTS** | **DEVICES** | **n.** | **Rated power kW** | **Rated efficiency** | **Working hours per year** | **Load factor** | **Energy consumed kWh** | **%** |
| **Department 1** | Device 1 | 10 | 55 | 0.92 | 500 | 1 | 29 8913 | |
| | Device 2 | 20 | 4 | 0.85 | 4000 | 0.8 | 301 176 | |
| | Device 3 | 15 | 10 | 0.9 | 4000 | 0.9 | 600 000 | |
| **Total Dept.1** | | | 780 | | | | 1 200 089 | 17.5 |
| | | | | | | | | |
| **Department 2** | Device 1 | 1 | 500 | 0.85 | 3500 | 0.5 | 1 029 411 | |
| | Device 2 | 20 | 15 | 0.9 | 4000 | 1 | 1 333 333 | |
| | Device 3 | 5 | 7.5 | 0.8 | 4500 | 0.9 | 189 844 | |
| | Device 4 | 10 | 2 | 0.75 | 1500 | 0.8 | 32 000 | |
| | Device 5 | 3 | 150 | 0.92 | 3000 | 0.95 | 1 394 022 | |
| **Total Dept. 2** | | | 1307 | | | | 3 978 611 | 58.1 |
| | | | | | | | | |
| **Department #.** | Device . | | … | … | … | … | … | … |
| | | | | | | | | |
| **TOTALS** | | | 3250 | | | | 5 425 000 | 100.0 |

**Table 8.8: A simple electric model**

'n.' in column 'A' represents the number of identical devices (under both a technical and an operating point of view) present in that department.

The 'energy consumed' in column 'F' is given by multiplying the number of devices x rated power x working hours x load factor and dividing by rated efficiency:

$$F=\frac{A \times B \times D \times E}{C} \qquad \text{Equation 8.4}$$

By adding all energies consumed in each department, the total energy consumed by the entire plant can be calculated.

If the context studied is not so broad or complex, this kind of model could be adequate to detect the areas where energy saving possibilities are most likely to be found. It is sufficient to direct attention to the distribution of electricity consumptions for each department, shown in column 'G'. It is very likely that a series of actions to improve energy efficiency will be found in those departments where consumption of energy is the highest, while departments whose consumption is low can be neglected or taken into account later.

When the context deserves it (because the cycle of production is extremely complex, or when energy data have never been collected before) it would also be useful to collect following data to identify energy saving actions, e.g.

- for motors and drives:
    - kind of machinery driven by the motor (compressor, fan, pump, etc.)
    - identification code
    - manufacturer and model name
    - type of motor
    - installation year, or residual life
    - number of rewinds carried out so far
    - type of speed control if existing
    - type of mechanical transmission
    - possibility to shift the operation to different times (to exploit more favourable electricity tariffs at specific times or on specific days).

- for lighting apparatus:
    - type of lighting body
    - number of lamps in a body
    - number of lighting bodies
    - type of lamps
    - rated power of the lamp
    - efficiency of the lamp
    - kind of ballast (iron, copper or high frequency).

### Example 2. Thermal energy models

Though all previous data should be collected, in the first level thermal model ('generators' side') only a few of them must be taken into account as in the drawing of an electric model (see Table 8.9):

| | | A | B | C | D | E | F | G |
|---|---|---|---|---|---|---|---|---|
| **PROCESS** | **Device** | **n.** | **Rated power kWth** | **Rated efficiency** | **Working hours per year** | **Load factor** | **Energy consumed $Nm^3$ $CH_4$** | **%** |
| **Phase 1 (e.g. burning)** | **Big kilns** | 4 | 800 | 0.85 | 7700 | 0.8 | 2 417 000 | |
| | **Small kilns** | 5 | 600 | 0.85 | 7700 | 0.8 | 2 266 000 | |
| **Total Phase 1** | | | 6200 | | | | 4 683 000 | 76.5 |
| **Phase 2 (e.g. heat production)** | **Hot water boiler** | 2 | 2500 | 0.92 | 1000 | 0.5 | 283 200 | |
| | **Steam boiler** | 2 | 1000 | 0.92 | 7000 | 0.5 | 793 200 | |
| | **Hot water boiler** | 2 | 1000 | 0.92 | 1600 | 0.5 | 181 200 | |
| **Total Phase 2** | | | 9000 | | | | 1 257 600 | 20.5 |
| **Phase 3 (e.g. Services)** | **Spray drier** | 1 | 400 | 0.7 | 200 | 1 | 11 900 | … |
| | **Hot air generator** | 1 | 400 | 0.85 | 1600 | 0.5 | 39 200 | |
| | **Small heaters** | 37 | 30 | 0.8 | 1600 | 0.5 | 115 700 | |
| | **Big heaters** | 2 | 60 | 0.8 | 1600 | 0.5 | 12 500 | 3.0 |
| **Total Phase 3** | | | 2030 | | | | 179 300 | |
| **TOTALS** | | | 3250 | | | | 6 119 900 | 100.0 |

**Table 8.9: Data in a thermal energy model (generators side)**

In this case, to make the comparison easier, the energy consumed has been estimated as $Nm^3$ of natural gas. The amounts of natural gas consumed are given, in this case, by:

$$F = \frac{A \times B \times D \times E \times 3600}{C \times 34\,500}$$

Where

| | |
|---|---|
| • 3600 | conversion factor from kWh to kJ |
| • 34 500 | is the net heating value for natural gas ($kJ/Nm^3$). |

The first level thermal model ('generators' side') must be checked to see if the total amount of energy demand is equal to the total energy reported in the invoices for natural gas supply. If so, the model is reliable and useful to indicate the best areas in which to implement energy saving actions.

When assessing the thermal use of energy, second level models ('users' side') are also required to be built. To draw up such data sheets it is necessary to take a census of all machineries needing thermal energy in any form (hot water, steam, hot air, etc.) except fuel (taken into account in the first level model).

For every item of machinery, the following data should be collected:

- kind of thermal carrier needed
- hours/year of thermal demand
- load factor at which thermal energy is used
- rated thermal power.

Such data can be arranged in Table 8.10 as follows.

| | | A | B | C | D | E | F | G |
|---|---|---|---|---|---|---|---|---|
| **DEPARTMENTS** | **DEVICES** | **n.** | **Thermal carrier** | **Thermal power kWth** | **Working hours per year** | **Load factor** | **Energy request $Nm^3$ $CH_4$** | **%** |
| **Department 1** | Device 1 | 2 | Steam | 500 | 1000 | 1 | 104 200 | |
| | Device 2 | 1 | Steam | 125 | 500 | 0.8 | 5200 | |
| | Device 3 | 5 | Hot water | 75 | 5000 | 0.8 | 156 400 | |
| **Total Dept. 1** | | | | | | | 265 800 | 21.8 |
| **Department 2** | Device 1 | 1 | Steam | 75 | 2500 | 0.5 | 9800 | |
| | Device 2 | 20 | Hot air | 10 | 3000 | 1 | 62 500 | |
| | Device 3 | 5 | Steam | 50 | 2500 | 0.8 | 52 100 | |
| | Device 4 | 10 | Hot water | 5 | 1500 | 0.8 | 6300 | |
| | Device 5 | 3 | Steam | 25 | 3000 | 0.9 | 21 100 | |
| **Total Dept. 2** | | | | | | | 151 800 | 12.5 |
| **Department .** | Device. | | | | | | | |
| | | | | | | | | |
| **TOTALS** | | | | | | | 1 215 700 | 100.0 |

**Table 8.10: Data in a thermal energy model (users side)**

The second level model ('users' side') is useful to verify the match between the heat supplied by the utilities (boilers, heat generators, etc…) and the heat requested by the users. In this case, the amounts in column F are given by:

$$F = \frac{A \times C \times D \times E \times 3600}{34\,500}$$

In Table 3.4, the calculation was as follows:

1 257 600 + 179 300 = 1 436 900 $Nm^3$ of natural gas supplied.

In the second level model the calculation shows 1 215 700 $Nm^3$ of natural gas demand. The 15 % difference is due to the efficiencies at following steps: heat generation, distribution piping and regulation, and final use.

If this difference is acceptable, then the two models can be considered as 'certified'; in the opposite case some correction (normally to the number of working hours or the load factors) is needed to reach convergence.

If the difference between the two amounts is big, this is due to a high level of losses in the production-distribution-use for different carriers (e.g. steam, hot water, etc.) In this case, different actions aiming to improve the energy efficiencies, for example in the field of insulations, of recovery of condensate, etc. are likely to be possible.

# ANNEX 7 AUDIT TOOLS

Many tools have been developed to 'standardise' contents and approaches of audits. Usually external audit companies have tailor-made tools, such as checklists to use in auditing procedures. The list below briefly reviews some of the tools. Many of these tools may overlap and it is the responsibility of the auditor to determine what is necessary to use. The above-mentioned tools are general, and not specific to a target sector or an energy audit model, but their usefulness frequently corresponds to one or several phases of the audit survey:

- **audit guide or audit handbook, energy management handbook**: this is a core component of an energy audit scheme, which is the basis of training sessions and is targeted essentially to auditors. It explains and describes how an audit is to be made, how the calculations are to be conducted, and the types and contents of the most frequently proposed energy conservation options (ECOs). Although auditors are assumed to have some background in thermodynamics (and also electrical engineering), these handbooks frequently entail a section of reminders of these energy related topics
- **energy checks, checklists or walk-through guides:** associated with energy audit models of the scanning type, these supporting documents are developed in order to facilitate the work of the auditor, assuring at the same time both quality and rapidity of the survey. They are primarily intended for energy auditors but can also be used as self-auditing tools for those energy managers in industrial premises who intend to start an in-house energy management process before requesting external assistance
- **calculation methods and software:** also known as energy models. These are another core component of energy audit schemes, and are associated with analytical energy audit models. Their primary objective is to help the auditor in the quantitative assessment of energy saving potentials and evaluation of investment costs and paybacks. The use (by an auditor) of a recommended or certified calculation tool (provided it is used correctly) assists with achieving quality results for the audit client
- **data collection form(s):** generally associated to the calculation tool for which they constitute the input data, this type of support document helps the auditor in collecting all the necessary information for the survey. It will be part of the final report and will also contribute to facilitating the follow-up of the site energy features and the interpretation of the audit results and recommendations
- **report templates:** as for data collection forms, report templates are also frequently associated with the calculation tool where output results are integrated in the report. As the report is the deliverable of the audit, using a template helps all the participants to make the most profitable use of the audit service and produce good quality audit reports
- **checklist for quality control of audit reports:** this checklist is a document which can be used at both company level and at auditor level (self-check). It is a complement of, or an alternative to, report templates and a practical translation of energy audit models: the expected results specified in the energy audit model should be in the report and the checklist is an easy way to verify that the work has therefore been done according to the specifications
- **target values or benchmarking:** (see Section 2.12) these key figures can be used to initiate the need for energy audits, they are also used by the auditors as technical data to justify their recommendations in the case of simplified audits
- **databases on energy conservation options (ECOs):** one difficult part of the audit is having detailed information on costs and consequences of energy saving recommendations. A database of ECOs encompassing this information will save a lot of time and money for the auditor/operator and thus help lower the cost of the audits with a maintained quality. Keeping the data up-to-date requires quite a lot of work. An examples is:
  - default data: these can contribute to detailed audits in checking calculations or replacing data difficult to meter or evaluate either way. They may be derived from databases (see above), reference data or experience gained from another site, audit, etc.

# ANNEX 8 BENCHMARKING

Austrian Energy Agency
Austrian Energy Agency's (AEA) report 'Energy benchmarking at the company level, company report diary' gives benchmarking factors other than specific energy consumption. For example, scores for using certain energy saving technologies (see Chapter 3):

- frequency of boiler checks (100 % of the plants reported frequent boiler checks)
- frequency of compressed air line checks (25 % of the plants systematically removed dead-legs from systems when the process is changed and 50 % of them occasionally check dead legs)
- using energy saving technologies (variable speed drives, energy efficient motors (EEMs), heat recovery, heat pumps and energy efficient lighting, boiler maintenance and compressed air).

However, note that this may drive a bottom-up approach (i.e. changing specific components) rather than assessing whole systems.

Scheme for SMEs in Norway
Norway has a web-based benchmarking scheme for SMEs. Benchmarking is based on comparing the specific consumptions (e.g. kWh/kg) of the companies. Specific consumptions are calculated according to the total energy use and total production of the site. To date, 43 different benchmark groups have been established among the 800 participating companies. Because one factory usually produces different products with different energy intensities, correction factors are used to normalise these differences.

Benchmarking covenants, Netherlands (A similar scheme operates in Flanders Province, Belgium)

In the Netherlands, long-term agreements (covenants) between the government and large companies (consuming over 0.5 PJ/year) are based on benchmarking. The covenants provide a framework for $CO_2$ emissions reduction (see Chapter 5).

A key example is the Dutch paper and board industry, with 26 manufacturing plants, and which is a substantial energy consumer in the Netherlands. Participating companies commit themselves to take energy reduction measures to bring their installations within the world top installations in their lines of industry. The world top in this context means the top 10 % of energy efficient installations. The national industry association played a vital role in the management of the benchmarking process and commissioned two consultants, one accounting and one engineering with experience of the industry.

The covenant prescribes that energy efficiency is calculated using the lower heating value of primary fuels used for all purposes at a location (e.g. steam and power generation, direct heating, combustion engines). Electricity drawn from, or supplied to, the national grid, is converted at a standard yield of 40 %.

The consultants evaluated energy performance information of paper mills all over the world, available in the public area as well as from their own databases. Since Dutch mills only operate the downstream end of the papermaking process (without pulp manufacture) the evaluation was confined to units of operation in that part of the process. The following generic units were benchmarked:

- stock preparation
- paper machine
- final processing (winding, cutting, packing, etc.)
- energy conversion
- general utilities and auxiliaries.

Performance information from different units was made comparable by the introduction of correction factors. These were, for instance, used for aspects like raw material composition, deinking, sizing, waste water treatment facilities and power configuration.

A best practice approach was developed for six sub segments of the industry depending on the end-product:

- newsprint
- printing and writing
- tissue
- container board
- carton board and folding boxboard
- small speciality paper mills.

Glass industry benchmarking

The glass industry is investigating several methods to identify the most energy effect glass-melting operations:

- best practice methods and application of energy balances
- determination of the theoretical energy or enthalpy demand and the practically lowest level of energy consumption
- benchmarking of specific consumption of industrial glass furnaces
- development of new melting and fining techniques.

Since 1999, data on about 250 glass furnaces have been collected for the purpose of benchmarking for the different glass industry sectors. Unfortunately, it was not possible to obtain complete and reliable data worldwide; however, data have been obtained from Europe, Japan, US, Canada and Turkey.

Different ranking methods could be used:

- from lowest specific energy consumption to the highest and defining the world top 10 % furnaces
- best in region, using the average of furnaces in a region as the benchmark
- the lowest achievable energy consumption of a glass furnace applying all best available techniques (from literature, suppliers and the GLS BREF).

A theoretical energy demand has been calculated and thermodynamic models are available. At a temperature of 1400°C, a typical soda-lime-silica batch demand is about 0.52 MJ/kg of glass for the chemical reactions and 1.75 MJ/kg for heating the glass melt.

Parameters determining energy efficiency were found to be:

- cullet (waste glass) fraction in the batch
- raw material selection
- age and type of furnace
- specific pull and total pull rate
- furnace age
- electric boosting
- batch preheating
- other factor such as:
    - furnace design and insulation
    - excess air balance
    - type of burner and fuel.

The data were normalised to primary energy to take account of the electricity used and the oxygen generation for the oxy-furnaces, and for the cullet level in feed. Other parameters could arguably be normalised, e.g. the furnace could be normalised to 0 years (i.e. new), but this would then not take account of cold repairs during the campaign to improve energy efficiency, etc.

As a result the 10 % level was identified at 4285 MJ/t of molten glass, with a difference between the most energy efficient furnace and the middle ranking furnace (50 % ile) was 25 %. Best practice for container and float glass was identified.

The study also reached important conclusions included in Applicability, above.

# ANNEX 9 OTHER TOOLS FOR USE AT A SITE LEVEL

## Checklists

Checklists can be:

- general (see good housekeeping, Section 2.6)
- specific to see activities (see auditing, Section 2.8)
- specific for some technical systems (utilities and buildings)
- specific for some industrial branches (production processes).

They may also be used to identify compliance or energy saving opportunities with best practices in energy management or in technologies (see Implementation and operation of procedures in Section 2.1, and Operational Excellence, Section 2.2.5).

## Good housekeeping

Good housekeeping measures are low cost activities typically paid from yearly revenue budgets of managers and do not require capital investments. Typical examples include switching off motors when not needed, ensuring that equipment operates properly, cleaning fouled surfaces and pipes and having regular maintenance.

## E-learning

See also training, in Section 2.3. E-learning dealing with energy management and energy efficiency issues in the industrial sector is still developing. There are few existing and operational sites throughout the world which offer a comprehensive guide on matters like energy management, energy efficiency, best practices, energy audits, energy benchmarking and checklists. The sites usually may contain one or more of these topics, or may be aimed at non-industrial users (e.g. commerce, SMEs, householders). Some free examples are:

- US EPA and DOE joint programme:
  http://www.energystar.gov/index.cfm?c=business.bus_internet_presentations

- UK resource:
  http://www.create.org.uk/

Others are fee-paying and may be part-funded by national agencies, e.g.:

http://www.greenmatters.org.uk/
http://www.etctr.com/eetp/home.htm

There is a large amount of material available on the internet. Two further options to construct an e-learning scheme have been identified:

- to make it an interactive step-by-step learning tool for energy management
- alternatively or additionally, include links to case studies, checklists and guidelines and to general energy efficiency technologies.

# ANNEX 10 CHAPTER 3 EXAMPLES

## Examples from Steam

Insulating a single 100 mm valve controlling steam at 800 kPa (8 bar) (175 ºC) located indoors would reduce heat losses by 0.6 kW. This would reduce boiler fuel costs by EUR 40/year (LOW?) and give an energy saving of 6 MWh/year.

Johnson Matthey Catalysts in Teesside, UK: the fitting of insulation jackets to valves and flanges have resulted in:

- annual energy savings of 590MWh
- carbon savings of 29 tonnes/year
- payback period of 1.6 years.

### Preheating feed-water including using economisers (Section 3.2.4)

**Example 1:**

An economiser might be used for a gas-fired boiler with a production of 5 t/h steam at 20 barg.

The boiler produces steam with an output of 80 % and during 6500 hours per year. The gas will be purchased at a cost of EUR 5/GJ.

The economiser will be used to preheat the fresh boiler water before it flows to the degasser. Half of the condensate will be recovered, the other half will be supplemented with fresh water. This means the economiser can provide an improvement of 4.5 %.

The current use of the boiler is:

6500 h/yr x (2798.2 – 251.2) kJ/kg x 5 t/h x 5/GJ = EUR 517 359/yr
0.80 x 1000

The annual operational cost is reduced with the installation of the economiser to:

6500 h/yr x (2798.2 – 251.2) kJ/kg x 5 t/h x 5/GJ = EUR 489 808/yr
0.845 x 1000

The revenue thus amounts to EUR 27 551/yr.

**Example 2:**

A boiler generates 45 000 lb/h of 150 psig steam by burning natural gas. Condensate is returned to the boiler and mixed with makeup water to yield 117 ºF feed-water. The stack temperature is measured at 500 ºF. The boiler operates 8400 h/year at an energy cost of 4.50$/ MMBtu. By installing an economiser the energy savings can be calculated as follows:

Enthalpy values:
For 150 psig saturated steam: 1195, 50 Btu/lb
For 117 ºF feed-water: 84.97 Btu/lb

Boiler thermal output = 45 000 lb/h x (1195, 50 - 84.97 )Btu/lb = 50 million Btu/hr

The recoverable heat corresponding to a stack temperature of 500F and a natural gas-fired boiler load of 50 MMBtu/h is read from the table xy as 4.6/MMBtu.

Annual savings = 4.6 MMBtu/h x 4.50 $/ MMBtu x 8400 h/year = 173 880 $/ year = 197 300 EUR/year (1 $= 1.1347 EUR, conversion date 1st January 2002)

### 3.2.5 Prevention and removal of scale deposits on heat transfer surfaces

See ANNEX A (example A3)

Example 1:
A steam boiler yearly uses 304 000 $Nm^3$ natural gas and has an average annual use of 8000 hours. If a scale of 0.3 mm thick is allowed to form on the heat changing surface, then the heat transfer will be reduced by 2.9 %.

The increase in operating costs per year compared to the initial situation is:

304 000 $Nm^3$/year x 2.9 % x EUR 0.15/$Nm^3$ = EUR 1322 per year.

Example 2:
A boiler yearly uses 450 000 (MMBtu) of fuel while operating for 8000 hours at its rated capacity of 45 000 pounds per hour (lb/h) of 150-psig steam. If scale 1/32nd of an inch thick is allowed to form on the boiler tubes, and the scale is of "normal" composition, the table indicates a fuel loss of 2 %. The increase in operating costs, assuming energy is priced at 3 $/ MMBtu, is:

Annual Operating Cost Increase = 4 500 000 MMBtu/year x 3 $/ MMBtu x 0.02 = 27 000 $ = 30 637 EUR (1 $= 1.1347 EUR, conversion date 1st January 2002)

### 3.2.6 Minimising blowdown

**Example 1**
An automated blowdown control system is installed on a flame pipe boiler, which generates steam at 25 bar for 5500 hours a year. The blowdown system will reduce the blowdown rate from 8 to 6 %. The boiler provides 25 tonnes of steam per hour and its boiler efficiency amounts to 82 %. The gas price is EUR 5/GJ.

The make-up water is supplied at 20°C, and costs EUR 1.3 per tonne (including purification). The price for discharging waste water is EUR 0.1 per tonne.

Assuming that the condensate does not return, the blowdown only needs to be determined based on the flow of fresh water as return condensate does not contain any salts. The conductibility of fresh water is 222 µS/cm. This is an indication of the amount of dissolved salts in the water. Make-up water may have a maximum conductibility of 3000 µS/cm.

The blowdown rate (B) is thus calculated as follows:

Quantity of salts in = quantity of salts out
(25 000 + B) x 222 = B x 3000

So the blowdown rate is: 1998 l/hr or 8 %.

The initial quantity of fresh make-up water is:

25 000 kg/h/(1 – 0.8) = 27 174 l/h

After installation of the blowdown control system this becomes:

25 000 kg/h/(1   0.06) = 26 596 l/h, the difference is 578 l/h.

The enthalpy of make-up water at 25 barg is: 972.1 kJ/kg.

The enthalpy of feed-water at 20°C at atmospheric pressure is: 419.0 kJ/kg.

The difference thus is 553.1 kJ/kg.

Savings on fuel costs thus amount to:

5781 l/h x 5500 h x 553.1 kJ/kg x EUR 5/GJ = EUR 1072/yr
0.82 x 1 000 000

Savings were also made on purification and blowdown costs.

The quantity of water saved amounts to: 578 l/h x 5500 h/yr = 3179 t/yr.

This represents an avoided cost of EUR 4451/yr.

The installation thus generates annual profits of EUR ~~15172~~. surely EUR 5523

**Example 2**
Assume that the installation of an automatic blowdown control system reduces your blowdown rate from 8 % to 6 %. This example assumes a continuously operating natural-gas fires, 150 psig, 100 000 lb/h steam boiler. Assume a makeup water temperature of 60 ºF, boiler efficiency of 82 %, with fuel valued at 3 $ per million Btu (MMBtu), and the total water, sewage and treatment costs 0.004 $ per gallon. The total annual cost savings are:

Boiler feed-water: Initial = 100 000 / (1-0.08) = 108 695 lb/h
Final = 100 000 / (1-0.06) = 1 069 383 lb/h
Makeup Water Savings = 108 695 – 1 069 383 = 2312 lb/h
Enthalpy of boiler water = 338.5 Btu/lb; for make-up water at 60 ºF = 28 Btu/lb
Thermal Energy savings = 338.5 -28 = 310.5 Btu/lb

Annual Fuel Savings = 2312 lbs/h x 8760 h/year x 310.5 Btu/lb x 3 $ /MMBtu / 0.82 x 106 = 23 007 $

Annual Water and Chemical Savings = lbs/h x 8760 h/year x 310.5 Btu/lb x 0.004 $ /gal / 8.34 lbs/gal = 9714 $

Total savings = 23 007 $ + 9714 $ = 32721 $ = 37 128.11 EUR (1 $= 1.1347 EUR, conversion date 1st January 2002)

### 3.2.7 Recovering heat from the boiler blowdown

Example 1 (See ANNEX A, example A5)

A heat exchanger is installed between the blowdown pipe of a boiler and the supply of fresh make-up water. The boiler yearly works for 7600 hrs at a pressure of 10 barg and has an efficiency of 82 %. The boiler has a blowdown rate of 6 % and is natural gas fired at a cost of EUR 4/GJ. The supply of fresh make-up water is at 5.3 t/h.

For every 10 t/h of steam at a 6 % blowdown rate, the efficiency profit of 368 MJ/h is achieved (see Table xy4). To reach this profit value a supply of fresh make-up water of 5.3 t/h is needed. This leads to efficiency profits of 5.3/10 x 368 = 195 MJ/h.

This leads to the following savings:

| | |
|---|---|
| 7600 h x 195 MJ/h x EUR 4/GJ | = EUR 7229/yr |
| 1000 x 0.82 | |

## 3.2.8 Insulation on steam pipes and condensate return pipes

Example

In a plant where the value of steam is 4.5 $ /MMBtu, a survey of the steam system identified 1120 feet of bare 1-inch diameter steam line and 175 feet of bare 2-inch line both operating at 150 psig. An additional 250 feet of bare 4-inch diameter line operating at 15 psig was found. From the table, the quantity of heat lost per year is:

1-inch line: 1120 ft x 285 MMBtu/ yr per 100 feet = 3192 MMBtu/yr
2-inch line: 175 ft x 480 MMBtu/ yr per 100 feet = 840 MMBtu/yr
3-inch line: 175 ft x 415 MMBtu/ yr per 100 feet = 1037 MMBtu/yr

Total Heat Loss = 3192 + 840 +1037 = 5069 MMBtu/yr

The annual operating cost savings from installing 90 % efficient insulation is:

0.90 x 4.5 $ /MMBtu x 5069 MMBtu/yr = 20 530 $ = 23 295.13 EUR

(1 $= 1.1347 EUR, conversion date 1st January 2002)

### 3.2.8.1 Installation of removable insulating pads on valves and fittings

Using the table 3.2.8.1, the annual fuel and cost savings from installing a 1-inch thick insulating pad on an uninsulated 6-inch (150 mm) gate valve in a 250 lb/psig saturated steam line (406 ºF) can be calculated. Assume continuous operation with natural gas at a boiler efficiency of 80 % and a fuel price of 4.5 $ /MMBtu:

Annual Fuel Savings = 5992 Btu/h x 8760 h/year x 1/0.80 = 65.6 MMBtu/year

Annual Cost Savings = 65.6 MMBtu/year x 4.5 $ /MMBtu = 295 $ per 6-inch gate valve = 334.73 EUR (1 $= 1.1347 EUR, conversion date 1st January 2002).

### 3.2.10 Implementing a control and repair programme for steam traps

**Example 1.**

The amount of steam lost can be estimated for a steam trap as follows:

$$L_{t,y} = \frac{1}{150} \text{ x } FT_{t,y} \text{ x } FS_{t,y} \text{ x } CV_{t,y} \text{ x } h_{t,y} \text{ x } \sqrt{P_{in,t}^2 - P_{out,t}^2}$$

Where:

- $L_{t,y}$ is the amount of steam that steam trap t is losing in period y (tonne)
- $FT_{t,y}$ is the operating factor of steam trap t during period y
- $FS_{t,y}$ is the load factor of steam trap t during period y
- $CV_{t,y}$ is the flow coefficient of steam trap t during period y
- $h_{t,y}$ is the amount of operating hours of steam trap during period y
- $P_{in,t}$ is the ingoing pressure of steam trap t (atm)
- $P_{out,t}$ is the outgoing pressure of steam trap t (atm).

The operating factor $FT_{t,y}$ follows from Table 8.11.

| | Type | FT |
|---|---|---|
| **BT** | Blow through | 1 |
| **LK** | Leaks | 0.25 |
| **RC** | Rapid cycle | 0.20 |

**Table 8.11: Operating factors for steam losses in steam traps**

The load factor takes into account the interaction between steam and condensate. The more condensate that flows through the steam trap, the less space there is to let through steam. The amount of condensate depends on the application as shown in Table 8.12 below:

| Application | Load factor |
|---|---|
| Standard process application | 0.9 |
| Drip and tracer steam traps | 1.4 |
| Steam flow (no condensate) | 2.1 |

**Table 8.12: Load factor for steam losses**

Finally the size of the pipe also determines the flow coefficient:

$CV = 3.43\ D^2$
where D = the radius of the opening (cm).

An example calculation is:

- $FT_{t,y} = 0.25$
- $FS_{t,y} = 0.9$ because the amount steam that passed through the trap is condensed, but correct in comparison with the capacity of the steam trap (*Table 3 above)*
- $CV_{t,y} = 7.72$
- D = 1.5 cm
- $h_{t,y} = 6000$ hours per year
- $P_{in,t} = 16$ atm
- $P_{out,t} = 1$ atm.

The steam trap thus loses up to 1110 tonnes of steam per year.

If this occurs in a company where steam costs EUR 15/tonne, then the final loss would amount to: EUR 16 650 per year.

If steam is escaping fully rather than leaking, costs might rise to up to EUR 66 570 per year.

These losses rapidly justify the setting up of an effective management and control system for all the steam traps in a company.

**Example 2:**
In a plant, the value of steam is 4.50 $ / 1000 lb. A trap on a 150 psig steam line is stuck open. The trap orifice is 1/8 inch in diameter. The table shows the estimated steam loss as 75.8 lb/h. By repairing the failed trap, annual savings are:

Savings = 75.8 lb/h x 8.76 h/year x 4.50/1000 lb = 2988 $ /year = 3390.45 EUR

(1 $= 1.1347 EUR, conversion rate 1st January 2002)

### 3.2.12 Re-use of flash steam

*Example:* (See ANNEX A, examples A8 & A9)
A vent pipe with the following properties:

| | |
|---|---|
| Velocity of flash steam: | 300 ft/min |
| Diameter of vent pipe: | 4 inches |
| Hours of operation: | 8000 h/year |
| Boiler efficiency: | 82 % |
| Cost of fuel: | 4.5 $ /MMBtu |

A vent condenser could condense the flashed steam, transfer its thermal energy to incoming make-up water, and then return it to the boiler. Energy is recovered in two forms: hotter make-up water and clean, distilled condensate ready for use in the operation.

| **Energy Recovery Potential of a Vent Condenser** | | | | | |
|---|---|---|---|---|---|
| **Pipe Diameter (inches)** | **Energy Content, MMBtu/year*** | | | | |
| | **Steam velocity, feet/min** | | | | |
| | **200** | **300** | **400** | **500** | **600** |
| 2 | 90 | 140 | 185 | 230 | 280 |
| 4 | 370 | 555 | 740 | 925 | 1110 |
| 6 | 835 | 1250 | 1665 | 2085 | 2500 |
| 10 | 2315 | 3470 | 4630 | 5875 | 6945 |
| *Assuming continuous operation, 70 ºF make-up water, and condensed steam at 100 ºF | | | | | |

Referring to the table above, the potential energy recovered from the flashed steam is 555 MMBtu, based on 8670 hours of annual operation. The annual potential fuel cost savings are:

Annual Energy Recovered = 555 MMBtu / year x 8000 h/year / 8760 h/year x 1 / 0.82 = 618 MMBtu

Annual Potential Fuel Cost Savings = 618 MMBtu x 4.5 $ /MMBtu = 2781 $**= 3155.57 EUR
(1 $= 1.1347 EUR, conversion date 1st January 2002)

**Note that the annual fuel savings are per vent. Often, there are several such vents in a steam facility, and the total savings can be a significantly larger number. The additional heat exchanger cost still needs to be considered, but available literature shows a quick payback for the measure.

In the table below, the quantity of steam obtained per pound of condensate flashed is given as a function of both condensate and steam pressures.

| **High-Pressure Condensate Flashing** | | | | |
|---|---|---|---|---|
| **High-Pressure Condensate (psig)** | **Per cent of Condensate Flashed (lb Steam / lb Condensate)** | | | |
| | **Low-Pressure Steam (psig)** | | | |
| | **50** | **30** | **15** | **5** |
| 200 | 10.4 | 12.8 | 15.2 | 17.3 |
| 150 | 7.8 | 10.3 | 12.7 | 14.9 |
| 100 | 4.6 | 7.1 | 9.6 | 11.8 |
| 75 | 2.5 | 5.1 | 7.6 | 9.9 |

*Example:*

In a plant where the cost of steam is 4.5 $ /MMBtu, saturated steam at 150 psig is generated, and a portion of it is throttled to supply 30-psig steam. Assuming continuous operation, determine the annual savings of producing low-pressure steam by flashing 5000 lb/h of 150-psig condensate. The average temperature of the boiler make-up water is 70 ºF.

From the table above, when 150-psig condensate is flashed at 30 psig, 10.3 % of the condensate vaporises.

Low-pressure steam produced = 5000 lb/h x 0.103 = 515 lb/h

From the ASME Steam Tables, the enthalpy values are:

For 30-psig saturated steam = 1171.9 Btu/lb
For 70 ºF makeup water = 38.0 Btu/lb

Annual savings are obtained as follows:

Annual Savings = 515 lb/h x (1171.9 – 38.0) Btu/lb x 8760 h/year x 4.5 $ /MMBtu = 23 019 $ = 26 119.37 EUR
(1 $= 1.1347 EUR, conversion date 1st January 2002)

### 3.2.13 Minimising boiler short cycling losses

Example (See ANNEX A, example A10)

*Example:*

A 1500 hp (1hp = 33.475 Btu/h) boiler with a cycle efficiency of 72.7 % ($E_1$) is replaced with a 600 hp boiler with a cycle efficiency of 78.8 % ($E_2$). The annual cost savings can be calculated as follows:

Fractional Fuel Savings = $(1 - E_1 / E_2) = 1 – 72.7/78.8) \times 100 = 7.7\ \%$

If the original boiler used 200 000 MMBtu of fuel yearly, the savings from switching to the smaller boiler (given a fuel cost of 3.00 $ / MMBtu) are:

Annual Savings = 200 000 MMBtu x 0.077 x 3.00 $ / MMBtu = 46 200 $ = 52 422.56 EUR
(1 $= 1.1347 EUR, conversion date 1st January 2002)

## Examples in waste heat recovery

### Acid cleaning of heat exchangers

The plants adopting the known Bayer process to extract alumina from the raw material bauxite, named also alumina refineries, operate the caustic leaching of the ore at high temperatures, which can be as high as 250 C, like in the reference Italian alumina refinery (which will be described in this section) and in many others, or as low as 140 C, like in some western Australian plants, depending on the bauxite type.

The reaction or digestion-phase is followed by a depressurising phase in which, in a number of progressive flashing stages, the temperature and the pressure of the liquor decrease until atmospheric conditions are reached.

The flashed steam delivered in this phase is recovered by condensing it, shell side, into a series of shell and tube condensers where tube-side flows the caustic liquor returning to the reaction phase. The recovery efficiency of the flashed steam covers a very important role in the energy efficiency of the entire process, as the higher the recovery is, the lower the request of fresh steam to the digesters, and consequently the lower the fuel oil consumption of the process.

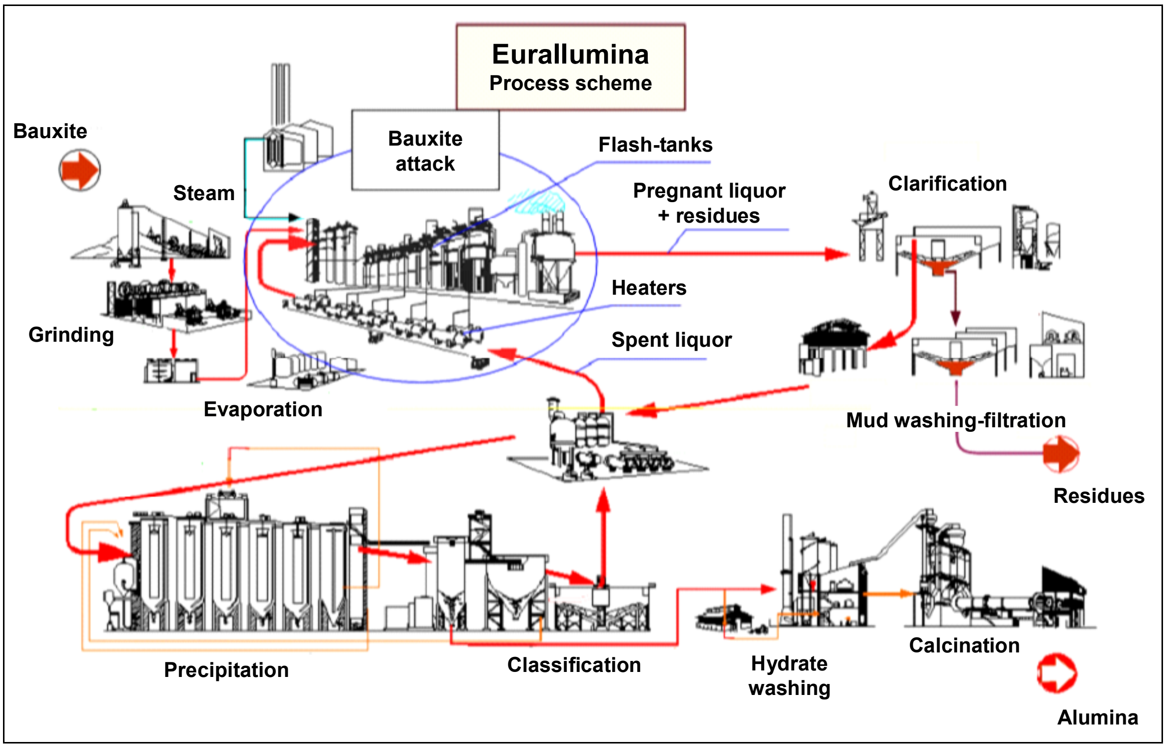

**Figure 8.13: Process scheme of Eurallumina alumina refinery**
**[48, Teodosi, 2005]**

### Description of the energy efficiency technique

The shell and tube heaters are subject to an acid cleaning routine, to renew the internal surface of the tubes and restore the heat transfer efficiency. The tubes are in fact subject to silica scaling precipitating from the process liquor, especially occurring at higher temperatures.

Notwithstanding a desilication treatment normally adopted by refineries, the silica level in the Bayer liquor is such that the scaling rate can seriously impact the recovery of the flashed steam and the energy efficiency.

The frequency optimisation of the acid cleaning routine is the way to improve the average heat transfer coefficient of the heaters and consequently reduce the fuel oil consumption of the process.

### Achieved environmental benefits especially including improvements in energy efficiency

The operating cycles of the heaters have been reduced from 15 to 10 days, and consequently the frequency of the tube acid cleaning routine has increased. This operating change has permitted the average heat transfer coefficient to increase, and the recovery of the flashed steam to improve. See Figure 8.14.

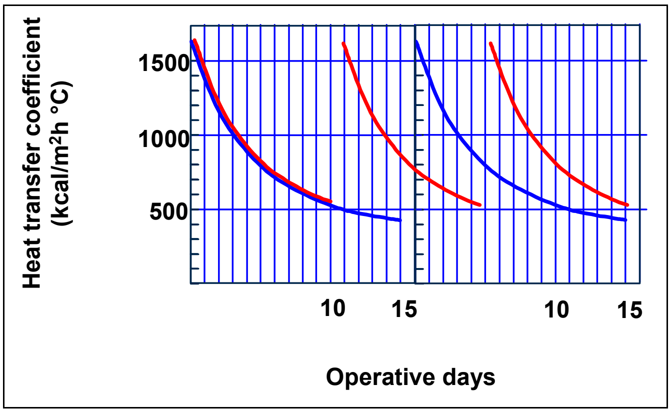

**Figure 8.14: Operative cycle of heaters**
**[48, Teodosi, 2005]**

### Cross-media effects

The only side-effect caused by the implementation of this technique can be represented by the additional quantity of exhausted acid relevant to the increased frequency of acid cleaning, to be finally disposed of. In the case of the alumina refinery, however, this does not create any environmental problems, as the exhausted acid resulting from the operation is disposed of together with the process residues, or the exhausted bauxite, which are alkaline. The mix of the two residues offers in fact the opportunity for a neutralisation of the process wastes (the so called red mud), before their disposal to the mud basin.

### Operational data

The performance data are those regarding the energy and oil consumptions which have been already mentioned. As far as emissions are concerned, the oil saved at the boilers turns out into a corresponding reduction of emissions from the boiler stack, evaluated around 10 000 tonnes $CO_2$/yr, and also 150 tonnes $SO_2$/yr before the adoption of the desulphurisation process, which took place in the refinery in 2000.

The technique of the tube acid cleaning must be supported by the preparation of the acid solution at the recommended concentration and with the addition of an appropriate corrosion inhibitor to protect the metal surface. A useful technique to improve the protection against the acid attack of the metal, during the acid circulation inside the tubes, is to circulate some cold water shell side, in order to avoid an uncontrolled temperature increase somewhere in the tubes.

### Applicability

The high temperature heaters in the reference refinery have been equipped with stainless steel tubes, in order to eliminate the phenomenon of tube leaks occurring. This choice was decided due to the importance covered for the process continuity by the production of good condensate, utilised as boiler feed-water. This factor also contributes in having long lasting heaters (for over 12 years) in spite of the frequent acid cleaning routine.

### Economics

The costs associated with the new procedure can be given by minor investment necessary for some facilities required by the increased cleaning frequency, as well as by the company to do the operation. The process savings are those reported in terms of oil saving and emissions reduction.

The improvement achieved in the energy efficiency of the system can be estimated in a reduction of the fuel oil consumption by around 3 kg/tonne alumina, which corresponds to 1.6 % of the process oil consumption. Given the production rate of the refinery which is around 1 Mtonne alumina/yr, the saving equates to 3000 tonnes of fuel oil per year.

### Driving force for implementation

Economic reasons.

### Examples

Eurallumina, Portovecompany, Italy.

### Reference information

[48, Teodosi, 2005]

## Surplus heat recovery at a board mill

### Description of the energy efficiency technique

Co-operation between municipality and industry is seen as an important way to increase energy efficiency. One good example of such co-operation is the one in Lindesberg, Sweden, a small municipality with about 23 000 inhabitants. AssiDomän Cartonboard in Frövi, Sweden has delivered surplus heat to the district heating network since 1998. This network is operated by Linde Energi AB (the municipality’s energy company). The deliveries cover over 90 % of the demand in the district heating system. The heat is distributed through a 17 km long transit pipe, with a forward and return pipe, to Lindesberg.

The board mill strives to reduce its environmental pollution and as a result the water consumption has decreased considerably in the last few decades. This has given the mill the possibility to produce a hot water surplus with a temperature of approx. 75 C. The hot water temperature is raised further in a flue-gas cooler before delivering heat to the district heating network, see Figure 8.15.

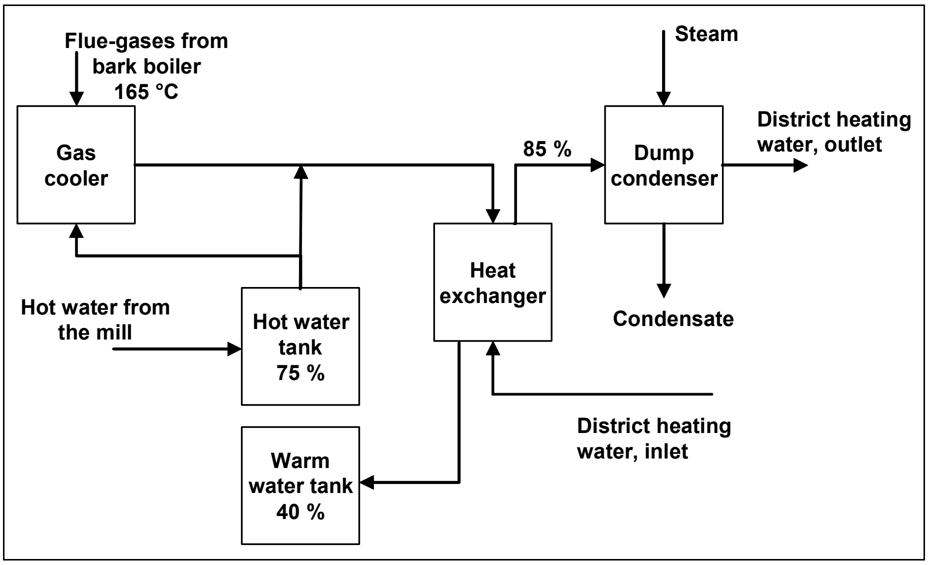

**Figure 8.15: Heat recovery system connected to the district heating system [20, Åsblad, 2005]**

With this arrangement of the heat recovery system, the excess heat from the mill, which has been collected by the secondary heat system, is utilised. Furthermore, the heat in the exhaust gases which would otherwise be discharged to the environment is utilised. The use of these heat sources does not normally increase the mill's fuel consumption. However, at peak loads a dump steam condenser is used in series, see Figure 4.18, and this steam usage results in increased fuel consumption in the mill (mainly bio-fuels).

### Achieved environmental benefits especially including improvements in energy efficiency

Before the board mill was connected to the district heating system, 65 % of the heat demand was supplied fossil fuels (fuel oil and LPG) while the remainder was supplied by an electricity driven groundwater heat pump (35 %). Today, the heat deliveries from the board mill cover more than 90 % of the district heating demand. The oil boilers at Linde Energi AB are used only during the coldest weather periods, i.e. about 2 weeks per year, and the heat pump is decommissioned.

Compared to the situation before AssiDomän was connected to the district heating system, the usage of fossil fuels has decreased by 4200 tonnes LPG and 200 $m^3$ fuel oil per year. Further, the electricity consumption has decreased by 11 000 MWh/year since the groundwater heat pump was taken out of service.

### Cross-media effects

Besides the obvious benefits of less usage of fossil fuels and electricity, decommissioning of the heat pump has decreased the release of ozone depleting substances to the air.

### Operational data

### Applicability

This type of co-operation is not limited to industry and municipalities. In an industrial park, this type of co-operation could be very fruitful. In fact it is one of the ideas behind the concept of eco-industrial parks.

**Economics**

The total investment cost amounted to EUR 15 million. Linde Energi AB received a grant from the Swedish government of EUR 2.3 million (15 % of total investment).

**Driving force for implementation**

The driving force was both economical and environmental concerns from both company and municipality. The timing was also right since the heat surplus in the mill was becoming a problem (risk of thermal pollution) and the heat pump in the district heating system needed an overhaul due to the mandatory out phasing of CFC-working fluids.

**Examples**

- Södra Cell Värö,Varberg
- Shell refinery, Göteborg
- Swedish Steel, Borlänge
- SCA, Sundsvall.

**Reference information:**

[20, Åsblad, 2005]

## Cogeneration

### Internal combustion engines (Reciprocating engines) Example: Bindewald Kupfermühle

- flour mill: 100.000 t wheat and rye/yr
- malthouse: 35.000 t malt /yr

CHP plant with stationary reciprocating engine (fuel saving 12,5 Mio. kWh compared to separated production with 12 Mio. $kWh_{el}$ and about 26 Mio. $kWh_{th}$.)

Technical data:

- fuel power: 2* 2143 $k_{fuel}$ (natural gas)
- electric power: 2*700 $kW_{el}$
- thermal power: 2* 1.200 $kW_{th}$
- fuel consumption? Ask
- power generation: about 10,2 Mio. $kWh_{el}$/a
- heat production: about 17,5 Mio. $kWh_{th}$/a
- full load hours : 7286 h/a
- power to heat ratio:0,58

Operating Data:

- start of operation: December 1991
- degrees of efficiency:
  - electric efficiency: 33 %
  - thermal efficiency: 56 %
  - fuel efficiency: 89 %

- amount of maintenance:
  - every thousand hours small maintenance
  - every 10.000 hours big maintenance
    - availability: about 90 %

- Cost effectiveness:
  - capital expenditures: 1,2 EUR million(including peripheral equipment)
  - payback period:
    - static: 5 years
    - dynamic: 7 years

- Benefit for the environment
  - fuel saving: 12.000 MWhfuel/year
  - CO2 saving: 2.500 t/year

**Reference information**
[64, Linde, 2005]

## Trigeneration

**Example: Barajas Airport, Madrid, Spain.**

Barajas Airport building's need of both heating and cooling is huge, the new airport terminal has a floor area of 760 000 m² (76 hectares). Applying the trigeneration concept, the engines are generating electricity as a baseload plant at top overall efficiency, instead of lying idle as emergency generators without contributing to the investment payback.

The overriding priority was to develop a cost efficient CHP plant that will be technically advanced, environmentally friendly, and that will guarantee the extremely high level of reliability necessary for this key facility in such an important location.

The solution was six Wärtsilä 18V32DF dual-fuel engines burning natural gas as the main fuel and light fuel oil (LFO) as the back-up fuel. However, the running hours in LFO are limited to a maximum of 200 hours per year, due to local environmental restrictions.

The trigeneration plant generates a net electrical output of 33 MW and is connected to both the airport's internal grid and the public grid. The plant provides electricity on a continuous basis, as well as heating for the new terminals during the winter, and cooling during the summer. Table 8.13 shows technical data for the CHP plant.

| Technical parameters | Data | Units |
|---|---|---|
| Power at generator terminals | 33.0 | $MW_e$ |
| Heat rate in gas mode | 8497/42.4 % | $kJ/kWh_e$ |
| Gross thermal power | 24.6 | $MW_{th}$ |
| Total thermal power | 30.9 | $MW_{th}$ |
| Heat recovery circuit | Water 120/80 | °C |
| ~~Total~~ Fuel efficiency of the CHP plant | 74 % | |
| Absorption chiller capacity | 18.0 | $MW_c$ |
| Total chiller capacity | 37.4 | $MW_c$ |
| Chilled water circuit | 6.5/13.5 | °C |
| Normal fuel | Gas | |
| Back-up fuel | Light fuel oil | |
| HT back-up cooling | Radiators | |
| LT and chiller cooling | Cooling tower | |

**Table 8.13: Technical data for the Barajas Airport trigeneration plant**

Six single-stage absorption chillers are installed in the power plant building. The chilled water is distributed to the consumers out in the new terminal through a separate piping system. The lithium bromide (LiBr) absorption chillers are powered by the 120 C heat recovery circuit and cooled by the cooling towers.

The Madrid Barajas Airport CHP plant has an oil-fired boiler for heating back-up/peaking and electrically driven compressors as chilling back-up/peaking.

The plant will sell excess power to the grid and be continuously interconnected to the national grid. The electric distribution system has high redundancy in order to cover all malfunctioning of the plant and still be able to feed the airport. If the gas supply fails, the engines will still be able to take full load running on oil.

**Reference information**
[64, Linde, 2005]

# ANNEX 11 EXAMPLES OF ESCOS

## Example 1: Replacement of a malfunctioning compressor in a compressed air system

Company A uses compressed air to dry semifinished products. But a malfunctioning compressor is preventing Company A from producing these at full capacity and the company is beginning to fall behind on its orders.

Company A decides to remedy this situation by integrating into their production line a compressor with comparable output that will be rented from a compressor provider or another supplier. After Company A's own compressor is repaired, the rented unit will be returned to its owner.

Table 8.14 shows advantages and drawbacks of renting equipment, from the standpoint of the energy user.

| Factors | Advantages | | Disadvantages |
|---|---|---|---|
| Capital expenditure | Low in the short term | | High in the long term |
| Level of expertise required by the organization | | | Relatively high |
| Personnel qualification level required | | | Relatively high |
| Maintenance and repair expenditures | | | Relatively high |
| Dependence on outside providers | | Moderate | |
| Expenditures for co-ordination and communication | | Moderate | |
| Security of energy supply | Relatively high | | |
| Scope of quality warranty | Relatively broad | Customer assumes responsibility for this | |
| Cost transparency | Relatively high | | |
| Term of contract | Short | | |
| Incentive to save energy | | | Relatively low |

**Table 8.14: Advantages and disadvantages of renting CAS equipment**

### 3.3.3.2 Technical facilities management

When an energy service provider (an ESCO) supplies technical facilities management services, it assumes responsibility for operation, maintenance and operating cost optimization of a specific facility.

Technical facilities management generally improves the efficiency of the facility under management since in most cases a smaller investment in measurement and control technology is involved. The facility remains the customer's property, and the only change is that the technical services are outsourced.

The energy service provider charges either for individual services or is paid a lump sum fee. The customer can also reduce its energy costs by sharing in the energy savings realized by the energy service provider, thus providing an incentive to use energy efficiently and economically.

Technical facilities management is most commonly used when the customer needs trouble-free and totally reliable operational performance and does not have a sufficient number of specialists on his staff.

Table 8.15 shows advantages and drawbacks of technical facilities management from the standpoint of the energy user:

| | **Advantages** | | **Disadvantages** |
|---|---|---|---|
| Capital expenditure | | | High |
| Expertise required by the organization | Low | | |
| Personnel qualification level required | Low | | |
| Maintenance and repair expenditures | Low | | |
| Dependence on outside providers | | | High |
| Expenditures for co-ordination and communication | | Moderate | |
| Security of energy supply | Relatively broad | | |
| Scope of quality warranty | Relatively broad | Customer assumes responsibility for this | |
| Cost transparency (applies to capital expenditures only and not to energy and other costs) | high | | |
| Term of contract | Short | | |
| Incentive to save energy | | | Relatively low |

**Table 8.15: Advantages and disadvantages of supply of CAS via an ESCO**

### Example 2: Cogeneration plant financing

Company C (a printing company) has decided to increase its production capacity, which will necessitate realization of a new cogeneration facility. After Company C settles on a solution, an energy service provider (which is also the facility manufacturer) obtains the financing, and does the planning and building for the facility under a 15 year contract. Financing is provided by the contractual charges that Company C pays the energy service provider-cum-facility manufacturer.

### 3.3.3.4 Final energy supply services (also referred to as installation contracting)

In this case, the energy service provider plans, finances, builds and operates the energy installation under contracts whose term generally varies from five to 20 years. During this time, the installation remains the property of the energy service provider. The customer enters into an energy services contract with the energy service provider for the purchase of a specific quality of energy at a specific price. Under this contract, the customer has no say in the financing, operation or maintenance of the installation.

The energy service provider’s costs are included in the overall price, which comprises a base price (monthly or otherwise) and a variable price depending on consumption, e.g. x number of euros per cubic meter of hot water. This arrangement provides the customer with an incentive to make economical use of the energy services purchased.

If the customer also uses the energy service provider’s distribution network, this should be included in the contract, which should also specify the energy transfer point or points. In this case, the energy service provider assumes direct responsibility for providing heated space and can thus cut down on end-use energy by trying to find the most efficient ways to supply final energy.

This energy services model is well suited for new buildings when energy services are to be outsourced; or for buildings whose energy systems need a top to bottom modernization that involves the replacement of old equipment /8/, e.g. supplying heat from modernized boiler systems.

Final energy is supplied in approximately 90 per cent of all energy services contracting scenarios.

Table 8.16 shows the advantages and drawbacks of final energy supply from the standpoint of the energy user.

| | **Advantages** | | **Disadvantages** |
|---|---|---|---|
| Capital expenditure | Low | | |
| Expertise required by the company | Low | | |
| Personnel qualification level required | Low | | |
| Maintenance and repair expenditures | Low | | |
| Dependence on outside providers | | High | |
| Expenditures for co-ordination and communication | | Moderate | |
| Security of energy supply | High | | |
| Scope of quality warranty | High | | |
| Cost transparency | Relatively broad | | |
| Term of contract | | | High |
| Incentive to save energy | High | | |

**Table 8.16: Advantages and disadvantages of energy via an ESCO**

# ANNEX 12 EXAMPLE OF TRANSPORT OPTIMISATION

### Description
Optimising product transport is a difficult task which has often to be supported by various studies investigating on alternative way to be more effective.

### Achieved environmental benefits
Reduction of gasoil (diesel) consumption and associated emissions.
Reduction in vehicle movements and associated environmental impacts (noise, congestion, etc).

### Cross-media effects
None

### Operational data
See Example plant.

### Applicability
On a case by case basis.

### Economics
For the example plant below: Indirect cost reduction of about 610 000 euros per year

### Driving force for implementation
A study clearly showed the potential to reduce costs and traffic impacts.

### Examples
Company : VICO SA located in Vic-sur-Aisne (France)
Activity : production of potato crisps and other products derived from potatoes
Quantity : 32 000 tonnes per year
Turnover : 114.4 EUR million/year

To deliver its products in 2500 selling points in France, VICO SA needed to use 9000 trucks movements per year. The products were packaged and placed on pallets with a height of 1.8 meters. In this manner, a standard truck (2.8 meters high) contained 38 pallets (on 1 level) and the filling rate was limited to 70 %. Following a feasibility study, the product packaging was changed to allow the storage on pallets of 1.4 meter high and loading on 2 levels. This enabled the number of truck movements to be reduced by 10 % and the kilometres travelled by 20 %.

Investment required: 76 224 euros
Payback time: 1.5 month
Test period: 3 months

Initial consumption: 686 030 l/year of gasoil
Consumption after implementation of the new packaging: 536 875 l/year of gasoil

Reduction by 22 % of the gasoil consumption

Indirect cost reduction for the company (transport is an external activity for this company): 610 000 euros per year

### Reference information
ADEME guide on good energy practices in industry (ref 3745)

# ANNEX 13 SUMMARY OF ENERGY EFFICIENCY TECHNIQUES AND BAT IN OTHER BREFS

### Importance of energy efficiency

The cement and lime industry is an energy intensive industry with energy typically accounting for 30–50 % of production costs (that is excluding capital costs). The key environmental issues associated with cement and lime production are air pollution and the use of energy.

### Most important processes/technologies related to energy efficiency

The clinker-burning process (for cement), or the lime-burning process, is the main source of emissions and is also the principal user of energy. The primary use of energy in cement manufacturing is as fuel for the kiln. The major users of electricity are the mills and the exhaust fans, which together account for more than 80 % of electrical energy use. On average, energy costs – in the form of fuel and electricity – represent 50 % of total production cost involved in producing a tonne of cement. Electrical energy represents approximately 20 % of this overall energy requirement.

The theoretical energy use for the burning process (chemical reactions) is about 1 700 to 1 800 MJ/t clinker. The actual fuel energy use for different kiln systems is about 3 000 to 6 000 MJ/t clinker.

The electricity demand is about 90–130 kWh/t cement (BREF 1, 23). The heat and electrical power use for calcining of limestone by lime kiln depends on the given kiln type, on the quality of the stone used and on the degree of conversion of calcium carbonate to calcium oxide.

The heat of dissociation of calcium limestone is 3 200 MJ/t. The net heat use per tonne of quicklime varies considerably with kiln design. Rotary kilns generally require more heat than shaft kilns. The heat use tends to increase as the degree of burning increases.

The use of electricity varies from a low range of 5–15 kWh/t of lime for mixed-feed shaft kilns, to 20–40 kWh/t for the more advanced designs of shaft kiln and for rotary kilns (BREF 1, 80).

### Energy recovery or energy saving techniques for the main processes

There are some energy saving and energy recovery techniques for the main processes in the cement and lime industry, principally for the clinker- and lime-burning processes. These techniques also have to be considered in the determination of BAT, so they will be described later in this chapter.

### Energy data and energy saving techniques for other processes

There are two more processes in the lime industry which have to be mentioned because they are not irrelevant to energy consumption: lime hydrating and lime grinding. For lime hydrating, the energy requirements to operate the hydrators, air classifiers and conveying equipment amount to approximately 5–30 kWh/t of quicklime.

The energy use for lime grinding varies from 4–10 kWh/t of quicklime for the coarser grades to 10–40 kWh/t of quicklime for the finer grades. The amount of energy required also depends on the equipment used (BREF 1, 81).

## Best available techniques (BAT)

Principally there are two different types of techniques, those which have to be considered in the determination of BAT (techniques not yet considered BAT) and others which are already considered as BAT. For the cement and lime industry these techniques are almost the same. Further, it is possible to divide the BATs into general techniques (primary measures) and more process specific ones.

## General BAT (cement industry)

The following measures can be considered as general techniques (primary measures) (BREF 1, 48):

A smooth and stable kiln process:

- process control optimisation, including computer-based automatic control systems
- the use of modern, gravimetric solid fuel feed systems.

Minimising fuel energy use by means of:

- preheating and precalcination to the extent possible, considering the existing kiln system configuration
- the use of modern clinker coolers enabling maximum heat recovery
- heat recovery from waste gas.

Minimising electrical energy use by means of:

- power management systems
- grinding equipment (high-pressure grinding rolls for clinker comminution) and other electricity based equipment with high energy efficiency.

## Process specific BAT (cement industry)

For new plants and major upgrades the best available technique for the production of cement clinker is considered to be a dry process kiln with multi-stage preheating and precalcination. The associated BAT heat balance value is 3 000MJ/t clinker.

## General BAT (lime industry)

The following measures can be considered as general techniques (primary measures) (BREF 1, 94):

A smooth and stable kiln process:

- process control optimisation.

Minimising fuel energy use by means of:

- heat recovery from exhaust gases to preheat the water for hydration of lime.

Minimising electrical energy use by means of:

- utilisation of mills and other electricity based equipment with high energy efficiency (high pressure roll mills).

### Process specific BAT (lime industry)

Replace or modify old kilns to reduce fuel energy use. Such modification range from minor modification (installation of heat exchangers) to major changes in the configuration of the kiln.

### Specific aspects for energy saving and energy recovery measures

There were no specific aspects concerning savings or recovery measures mentioned.

### Recommendation for the future

It could be useful to do a survey of the current abatement techniques, emissions and consumption and monitoring in the lime industry.

## Iron and steel industry

### Importance of energy efficiency

The iron and steel industry is a highly material- and energy-intensive industry. Additionally, emissions to the air and solid waste and by-products belong to the main environmental issues.

### Most important processes/technologies related to energy efficiency

In this BREF the principal ways of steel making are presented, namely in integrated steelworks and in electric arc furnaces. Because of the complexity of integrated steelworks, the main production steps (sinter plants, pelletisation plants, coke-oven plants, blast furnaces and basic oxygen steel making, incl. casting) are described separately. Therefore, all these production steps have to be considered important as regards energy efficiency.

However, the most energy consuming process unit in iron and steel production is the blast furnace. For a blast furnace using coal injection and top gas pressure recovery for electricity generation the total energy input amounts to 18.67 GJ/t pig iron (subdivided in coke = 12.4, powdered coal = 1.63, hot blast 4.52 and electricity 0.12) (BREF 2, 191).

The range of energy use within the sinter plants is about 1 125–1 920 MJ/t sinter (thermal energy) with an average consumption of 1 480 MJ/t sinter. Coke is the dominant sinter plant energy input (about 85 %), with electricity and gas supplying the remainder in equal amounts (BREF 2, 44).

In pelletisation plants, energy consumption differs depending on the type of plant. If the pelletisation plant is part of an integrated steelwork, the following energy consumptions are possible: coke oven gas (COG) 398.7 MJ/t, natural gas 209 MJ/t, coke 283 MJ/t. With stand-alone pelletisation plants, energy consumption is less: coal 213–269 MJ/t, oil 38–171 MJ/t (BREF 2, 95). Electricity varies from 51 MJ/t to 128 MJ/t independent of the type of plant.

In coke-oven plants energy consumption can be 3 200–3 900 MJ/t (blast furnace gas + COG) and 20–170 MJ/t (electricity). An energy balance for a coke-oven plant (without COG treatment) shows that with an input of 43 GJ/t coke the energy loss will amount to 3.33 GJ/t (<10 %) (BREF 2, 122, 127–128).

In the basic oxygen furnace (BOF), fuel is consumed to preheat and dry the converters after relining and repair. This thermal energy consumption is approximately 0.051 GJ/t liquid steel (LS). Electricity consumption is estimated at 23 kWh/t LS or 0.08GJ/t LS (BREF 2, 242).

Electric steel making is usually performed in an electric arc furnace (EAF). This furnace plays an important and increasing role in modern steel works in the European Union (35.3 % of the overall steel production). The total energy consumption amounts to 2 300–2 700 MJ/t (BREF 2, 281).

### Energy recovery or energy saving techniques for the main processes

For blast furnaces the following process-integrated measures belong to energy recovery or energy saving techniques (BREF 2, 194–198):

- direct injection of reducing agents. Energy savings can amount to 0.68 GJ/t pig iron or 3.6 % of the gross energy consumption of the blast furnace
- energy recovery from blast furnace gas. Approximately 5 GJ/T pig iron or 30 % of the gross energy consumption of the blast furnace
- energy recovery from top gas pressures. Energy savings are estimated at up to 0.4 GJ/t pig iron for a 15 MW turbine, which correspond to 2 % of the gross energy consumption of the blast furnace
- energy savings at the hot stove. About 0.5 GJ/t pig iron energy savings possible.

Within the sinter plants the following technique can be considered as an energy recovery technique:

- heat recovery from sintering and sinter cooling (BREF 2, 53–54)
  The recovered heat amounts to 30 % of the input heat. Two kinds of potentially reusable waste energy are discharged from the sinter plants: the sensible heat from the main exhaust gas from the sintering machines, and the sensible heat of the cooling air from the sinter cooler. The amount of waste heat recovered can be influenced by the design of the sinter plant and the heat-recovery system:
  - Sinter cooler waste heat recovery with conventional as well as Eos-sintering
  - (energy recovery = 18 % of the total energy input for the waste heat boiler)
  - Sinter cooler and waste gas heat recovery with sectional waste gas recirculation
  - (energy recovery = 23.1 % of the total energy input)
  - Strand cooling and waste heat recovery with partial waste gas recirculation

The following technique can be considered as an energy recovery technique in pelletisation plants (BREF 2, 99):

- recovery of sensible heat from induration strand. Approximately 67.5 MJ/t pellet or 4 % of gross energy consumption.

There are no energy saving techniques mentioned for coke-oven plants.

For the basic oxygen steel-making process the following techniques have to be considered as regards energy recovery and savings (BREF 2, 244-246):

- energy recovery from the BOF gas. When the energy from the BOF gas is recovered (waste heat recovery and/or BOF gas recovery), the basic oxygen furnace becomes a net producer of energy. In a modern plant, energy recovery can be as high as 0.7 GJ/t LS.

In the electric steel-making industry, several energy recovery and energy saving techniques are available (BREF 2, 295–301). The most important are:

- EAF process optimisation
- scrap preheating.

### Energy data and energy saving techniques for other processes

Because of the complexity of integrated steelworks and the structure of the iron and steel BREF, all relevant processes are discussed together with the most important one (blast furnaces) in the sections above.

### Best available techniques (BAT)

Principally there are two different types of techniques, those which have to be considered in the determination of BAT (techniques not yet considered BAT) and others which are already considered as BAT. In the iron and steel production industry these techniques are almost the same. All the techniques described above can be considered in the determination of BAT. In this section a short summary of the BATs concerning energy are presented.

### Process specific BAT for blast furnaces

- blast furnace gas recovery
- direct injection of reducing agents
- energy recovery of top blast furnaces gas pressure where prerequisites are present
- hot stoves (where design permits).

### Process specific BAT for sinter plants

- recovery of sensible heat.

### Process specific BAT for pelletisation plants

- recovery of sensible heat.

### Process specific BAT for basic oxygen steel making and casting

- BOF gas recovery and primary de-dusting.

### Process specific BAT for electric steel making and casting

- scrap preheating in order to recover sensible heat from primary off gas.

### Specific aspects for energy saving and recovery measures

The information concerning energy recovery or energy saving techniques is well presented and well structured.

# Non-ferrous metals industry

## Importance of energy efficiency

Energy consumption and the recovery of heat and energy are important factors in the production of non-ferrous metals. They depend on the efficient use of the energy content of sulphidic ores, the energy demand of the process stages, the type and supply method of energy used and the use of effective methods of heat recovery. There is a steady improvement in the environmental performance and energy efficiency of the industry over the last 25 years. The recycling performance of the industry is unmatched by any other industry.

## Most important processes/technologies related to energy efficiency

The most important processes and techniques within the non-ferrous metals industries related to energy efficiency are pyrometallurgical processes. They are highly heat intensive and the process gases contain a lot of energy.

## Energy recovery or energy saving techniques for the main processes

There are a lot of energy saving techniques described for the pyrometallurgical processes. A few examples are listed below:

- the steam produced can be used to produce electricity and/or for heating requirements
- use of the excess heat to melt secondary materials without the use of additional fuel
- use of oxygen enriched air or oxygen in the burners to reduce energy consumption by allowing autogenic smelting or the complete combustion of carbonaceous material
- separate drying of concentrates at low temperatures reduces the energy requirements
- heat recovery by using hot gases from melting stages to preheat the furnace charge. The recovered heat is approximately 4–6 % of the furnace fuel consumption
- collecting and burning carbon monoxide (produced in electric or blast furnaces) as a fuel for several different processes or to produce steam or other energy
- re-circulation of contaminated waste gas back through an oxy-fuel burner has resulted in significant energy savings
- use the heat content of process gases or steam to raise the temperature of leaching liquors.

## Energy data and energy saving techniques for other processes

There is a lot of information concerning energy consumption for the production of different nonferrous metals. Basically these metals are divided into ten groups and described separately. The following information is intended as an overview.

Copper: The energy use of the electrolytic process is most significant. The production energy (net) requirement for a number of processes using copper concentrate is in the range 14–20 GJ/t copper cathode. The energy consumed by the electro-refining stage of copper production is reported to be 300–400 kWh/t of copper (BREF 3, 214).

Aluminium: The main cost of producing primary aluminium is electricity (about 30 % of production costs). A typical range for energy consumption is 8–13.5 GJ/t aluminium (BREF 3, 283–284).

Lead and zinc: The energy consumption for the different lead and zinc processes varies to a large extent. Electricity is used for most of the processes (BREF 3, 359).

Ferro-alloys: The ferro-alloys industry is a major consumer of energy. The laws of thermodynamics limit the reduction of energy necessary for the smelting process. The reduction of the overall energy consumption is therefore in most cases only possible by using an efficient energy recovery system (BREF 3, 528–532).

Nickel: The energy used for the production of matte from sulphidic ores is reported to be in the range 25–65 GJ/t of nickel for ores containing 4–15 % Ni. The energy used in the various refining stages is reported to be 17–20 GJ/t of Ni (BREF 3, 631).

Ferro-alloy production is a high energy consuming process, because high temperatures are needed for the reduction of metal oxides and for smelting. In the non-ferrous metal BREF several different measures for energy recovery and the use of the recovered energy are listed (BREF 3, 546–548).

## Best available techniques (BAT)

Principally there are two different types of techniques, those which have to be considered in the determination of BAT (techniques not yet considered BAT) and others which are already considered as BAT. For the non-ferrous metals industry the BAT conclusion for energy recovery are:

- production of steam and electricity from the heat generated in waste heat boilers
- the use of the heat of reaction to smelt or roast concentrates or melt scrap metals in a converter
- the use of hot process gases to dry feed materials
- preheating of a furnace charge using the energy content of furnace gases or hot gases from another source
- the use of recuperative burners or the preheating of combustion air
- the use of the CO produced as a fuel gas
- the heating of leach liquors from hot process gases or liquors
- the use of plastic contents in some raw materials as a fuel, provided that good quality plastic cannot be recovered and VOCs and dioxins are not emitted
- the use of low-mass refractories where practicable.

### Specific aspects for energy saving and energy recovery measures

Most of the energy recovery or energy saving methods are site specific; therefore, not every technique can be implemented. Especially the techniques to recover heat vary from site to site. A number of factors are involved here, such as the potential uses for heat and energy on or near the site, the scale of operation, and the potential for gases or their constituents to foul or coat heat exchangers.

### Recommendation for the future

Additional efforts should be made to establish a basis of information including specific emission and consumption data. Energy usage should also be reported on this basis.

## Pulp and paper industry

### Importance of energy efficiency

The manufacturing of pulp and paper requires a large amount of process water and energy in the form of steam and electric power. Consequently, the main environmental issues associated with pulp and paper production are discharges to water, emissions to air and energy consumption.

### Most important processes/technologies related to energy efficiency

There are several different pulping and papermaking processes. Depending on the type of plant, a paper mill can be integrated with the pulping operations on the same site or can produce paper in stand-alone plants using purchased pulp. This BREF is divided into five main chapters describing the different processes, whereas energy aspects are discussed for each process separately. Evaporation and the maintenance of paper machines are the most important and most energy consuming processes.

*The kraft (sulphate) pulping process*
Within this pulping process the major part of the heat energy is consumed for heating different fluids and for evaporating water. Electrical energy is mostly consumed for the transportation of materials (pumping) and for the operation of the paper machine. The manufacturing of bleached kraft pulp consumes about 10–14 GJ/Adt of heat energy (steam for the production of electrical power not included). The consumption of electrical energy is 600–800 kWh/Adt, including the drying of pulp. The energy consumption for pulp drying is about 25 % of the heat energy and 15–20 % of the electrical energy. Over 50 % of the electrical energy consumption is used for pumping (BREF 4, 52–56).

*The sulphite pulping process*
A chapter for energy demand is reserved, but no data are available (BREF 4, 132).

*The mechanical and chemi-mechanical pulping process*
Energy consumption depends on the particular pulping process. For groundwood, for instance, the required energy varies between 1 100–2 300 kWh/t of pulp, while for refiner mechanical pulps the energy requirement amounts to 1 600–3 000 kWh/t of pulp. Finally, the thermo-mechanical pulps consume about 1 000–4 300 kWh/t of pulp (BREF 4, 182–185).

*Recovered paper processing*
Paper and board mills require substantial amounts of steam for heating water and large quantities of electricity for driving the machinery, and for pumping, vacuum, ventilation and waste water treatment. In paper mills, energy is usually the main factor in the operating costs. For example, in the Netherlands for recovered paper processing an average specific electricity consumption of 322 kWh/t (neglecting the difference in specific electricity consumption between RCF processing with and without de-inking) have been reported (BREF 4, 241–245).

*Papermaking and related processes*
The paper industry could be generally described as energy intensive. Energy is the third highest cost in the papermaking process, accounting for approximately 8 % of turnover. The total demand for energy (consumption) in the form of heat (steam) and electric power for a non-integrated fine paper mill has been reported as:

- process heat: 8 GJ/t (about 2 222 kWh/t)
- electric power: 674 kWh/t

More detailed information about the energy consumption of each single production step can be found in the BREF 4, pp. 336–342.

### Energy recovery or energy saving techniques for the main processes

The energy recovery and energy saving techniques for the main processes are discussed below and can be considered as BAT.

### Energy data and energy saving techniques for other processes

Most of the techniques to save energy are described below and can be considered as BAT. There is some information on the following processes:

*Sulphite pulping*
During the recovery process of chemicals, substantial amounts of energy can be produced (in recovery boilers) for steam and for power generation of the pulp mill.

*Mechanical and chemi-mechanical pulping*
Depending on the particular pulping process, it is possible to recover 20–30 % of energy either as steam or as hot water. For thermo-mechanical pulps the recoverable energy as steam can even reach 40–45 %. (BREF 4, 183).

### Best available techniques (BAT)

Principally there are two different types of techniques, those which have to be considered in the determination of BAT (techniques not yet considered BAT) and others which are already considered as BAT, resulting from the BAT conclusions. Further, the BATs are subdivided into general BAT concerning general aspects and measures and into process specific BAT regarding specific information.

## General BAT

The following measures can be considered as general techniques (primary measures) for all processes (BREF 4, 100):

- training, education and motivation of staff and operators
- process control optimisation
- sufficient maintenance of the technical units
- environmental management system which optimises management, increases awareness and includes goals and measures, process and job instructions, among other things.

## Process specific BAT for the kraft pulp and sulphite pulp mills

Measures for high heat recovery and low heat consumption (BREF 4, 110–111):

- high dry solids content of black liquor and bark
- high efficiency of steam boiler, e.g. low flue-gas temperature
- effective secondary heating system, e.g. hot water about 85ºC
- well closed-up water system
- relatively well closed-up bleaching plant
- high pulp concentration (MC technique)
- pre-drying of lime
- use of secondary heat to heat buildings
- good process control.

Measures for low consumption of electric power:

- as high pulp consistency as possible in screening and cleaning
- speed control of various large motors
- efficient vacuum pumps
- proper sizing of pipes, pumps and fans.

Measures for a high generation of electric power:

- high boiler pressure
- outlet steam pressure in the back-pressure turbine as low technical as is feasible
- condensing turbine for power production from excess steam
- high turbine efficiency
- preheating of air and fuel charged to boilers.

## Process specific BAT for the mechanical and chemi-mechanical pulp and paper mills

- implementation of a system for monitoring energy use and performance
- upgrading of equipment
- minimisation of reject losses by using efficient reject handling stages and reject refining
- use of effective heat recovery systems
- application of co-generation of heat and power where the power to steam ratio allows it.

## Process specific BAT for recovered paper processing paper mills

- implementation of a system for monitoring energy use and performance
- upgrading of equipment
- application for anaerobic waste water treatment.

### Process specific BAT for paper mills

- implementation of a system for monitoring energy use and performance
- more effective dewatering of the paper web in the press section of the paper machine by using wide nip pressing technologies
- use of energy efficient technologies, such as high consistency slushing, best practice refining, twin wire forming, optimised vacuum systems, speed adjustable drives for fans and pumps, high efficiency electric motors, well sizing of electric motors, steam condensate recovery, increasing size press solids or exhaust air heat recovery systems
- reduction of direct use of steam by careful process integration by using pinch analysis.

### BAT associated values

Energy efficient kraft pulp and paper mills consume heat and power as follows (BREF 4, 110–111):

- non-integrated bleached kraft pulp mills: 10–14 GJ/Adt process heat and 0.6–0.8 MWh/Adt of power
- integrated bleached kraft pulp and paper mills: 14–20 GJ/Adt process heat and 1.2–1.5 MWh/Adt of power
- integrated unbleached kraft pulp and paper mills: 14–17.5 GJ/Adt process heat and 1–1.3 MWh/Adt power.

Energy consumption associated with BAT for sulphite pulp and paper mills consume heat and power as follows:

- non-integrated bleached sulphite pulp mills: 16–18 GJ/Adt process heat and 0.7–0.8 MWh/Adt of power
- integrated bleached sulphite pulp and coated fine paper mills: 17–23 GJ/Adt process heat and 1.5–1.75 MWh/Adt of power
- integrated bleached sulphite pulp and uncoated paper mills: 18–24 GJ/Adt process heat and 1.2–1.5 MWh/Adt power.

Energy efficient mechanical pulp and paper mills consume heat and power as follows (BREF 4, 214–215):

- non-integrated CTMP: 2–3 MWh/Adt of power
- integrated newsprint mills: 0–3 GJ/Adt process heat and 2–3 MWh/Adt of electricity
- integrated LWC paper mills: 3–12 GJ/Adt process heat and 1.7–2.6 MWh/Adt power
- integrated SC paper mills: 1–6 GJ/Adt process heat and 1.9–2.6 MWh/Adt.

Energy efficient recovered paper mills consume heat and power as follows (BREF 4, 302–303):

- integrated non- deinked RCF paper mills: 6–6.5 GJ/Adt process heat and MWh/Adt of power
- integrated tissue mills with DIP plants: 7–12 GJ/Adt process heat and 1.2–1.4 MWh/Adt of power
- integrated newsprint or printing and writing paper mills with DIP plants: 4–6.5 GJ/Adt process heat and 1–1.5 MWh/Adt power.

Energy efficient non-integrated paper mills consume heat and power as follows (BREF 4, 411–412):

- non-integrated uncoated fine paper mills: 7–7.5 GJ/Adt process heat and 0.6–0.7 MWh/Adt of power
- non-integrated coated fine paper mills: 7–8 GJ/Adt process heat and 0.7–0.9 MWh/Adt of power
- non-integrated tissue mills based on virgin fibre: 5.5–7.5 GJ/Adt process heat and 0.6–1.1 MWh/Adt power.

### Specific aspects for energy saving and energy recovery measures

Some energy recovery and energy saving techniques are site specific. This means that it depends on the location of the mill whether certain techniques can be applied or not.

### Recommendation for the future

Little information is available on the assessment of energy efficient technologies and practical experiences of the results of implementation in the pulp and paper industry. When energy data and balances are reported the assumptions and conditions are often not sufficiently qualified. More work on this important issue and the derivation of production specific energy consumption figures are needed before the next review.

## Chlor-alkali manufacturing industry

### Importance of energy efficiency

The chlor-alkali process needs huge amounts of electricity. It is one of the largest consumers of electrical energy.

### Most important processes/technologies related to energy efficiency

In the European Union the chlor-alkali process was mainly used in mercury (amalgam) cell technology. Past mercury contamination of land and waterways from mercury plants is a major environmental problem at some sites. For many years, the mercury cell has been a significant source of environmental pollution, because some mercury is lost from the process to air and water, and shows up in products and waste.

Amalgam technology needs 3 560 ACkWh/t Cl2 (alternative current kilowatt hours/tonne of chlorine) assuming 50 % of caustic soda and before liquefaction of chlorine. The operation of a chloralkali plant is dependent on the availability of huge quantities of direct-current (DC) electric power, which is usually obtained from a high voltage source of alternating current (AC) (BREF 5, 36–37).

### Energy recovery or energy saving techniques for the main processes/technologies

There is little information about energy recovery or energy saving techniques within mercury cell technology. More information is given in the section on BAT.

### Energy data and energy saving techniques for other processes

In the chlor-alkali industry there are two other technologies that are lower in importance in the sense of frequency compared to mercury cell technology, but that are more interesting as concerns energy savings: asbestos diaphragm cell and membrane cell technology.

The total adjusted energy consumption of diaphragm technology is almost the same as that of mercury: 3 580 ACkWh/t Cl2. For membrane cell technology, the energy consumption amounts to 2 970 ACkWh/t Cl2 (BREF 5, 36–37).

### Best available techniques (BAT)

Principally there are two different types of techniques, those which have to be considered in the determination of BAT (techniques not yet considered BAT) and others which are already considered as BAT. A best available technique for the production of chlor-alkali is membrane technology. Non-asbestos diaphragm technology is also a BAT. The total energy use associated with BAT for producing chlorine gas and 50 % caustic soda is less than 3 000 ACkWh/t of chlorine when chlorine liquefaction is excluded, and less than 3 200 ACkWh/t of chlorine when liquefaction is included.

For mercury cell plants the best available technique is conversion to membrane cell technology. For diaphragm cell plants the best available technique is conversion to membrane cell technology or use of non-asbestos diaphragms.

### Specific aspects for energy saving and energy recovery measures

There are hardly any energy recovery or energy saving techniques described, because there are not many ways to save energy in mercury cell and diaphragm cell technology. The BAT is the conversion to membrane cell plants.

The chlor-alkali production technology is site specific, because of the difficulties in storage and transport of chlorine. Therefore, production usually takes place near the consumers. More than 85 % of the chlorine produced in the European Union is used on the same or on adjacent sites for other chemical processes.

The chlor-alkali BREF also contains information about national and international legislation within the European Union. The emphasis is on air emissions and discharges to water, while energy saving aspects are mentioned incidentally (BREF 5, Annex D, 136–137).

## Ferrous metals

### Importance of energy efficiency

The ferrous metal BREF is divided into three main parts (hot and cold forming, continuous hot dip coating lines, batch galvanising) which describe the different specific processes, and in one part techniques which might be applied to several subsectors are described. Energy consumption is a main environmental issue in the first two parts of the BREF together with air emissions (especially $NO_X$, $SO_2$) and dust emissions. In the third part energy use does not play an important role, which is probably why there is almost no information. The fourth part contains detailed technical descriptions and information on techniques which might be applied to several subsectors. Most of this information is concerned with the reduction of emissions, while energy aspects are inadequately discussed.

## Most important processes/technologies related to energy efficiency

*Part A: hot and cold forming*

There are several techniques and processes within hot and cold forming technology, but the most important concerning energy efficiency is the heating (reheating) and heat treatment process in furnaces. The energy consumption of the furnaces depends on several parameters such as the furnace design, throughput and shift patterns, the designed length of the recuperation zone in the furnace, the burner design, among others. The energy consumption for these furnaces was between 0.7 GJ/t to 6.5 GJ/t; with a typical range being 1–3 GJ/t (BREF 6, 63–65).

*Part B: continuous hot dip coating lines*

As in Part A, the most important process is reheating and heat treatment in furnaces.

*Part C: batch galvanising*

No special process is mentioned

## Energy recovery or energy saving techniques for the main processes

Almost every energy saving technique regarding reheating and heat treatment furnaces is considered as BAT (see section "Process specific BAT").

## Energy data and energy saving techniques for other processes

More processes and techniques concerning energy consumption in part A are:

| | |
|---|---|
| hot rolling | 72–140 kWh/t (deformation energy) |
| pickling of alloy | 0.015–0.3 GJ/t (electrical energy) |
| cold rolling | 0.2–0.3 GJ/t (electrical energy) |
| annealing of alloy | 0.06–0.12 GJ/t (electrical energy) |
| tempering | 0.02–0.15 GJ/t (electrical energy) |
| finishing (cutting, inspection, packing) | 0.02–0.04 GJ/t (electrical energy) |

and many more where energy data are not available.

There is limited information on energy saving techniques (BREF 6, 81–87).

In part B several other processes are mentioned; however there is only limited information on energy (consumption) (BREF 6, 276, 281–282):

| | |
|---|---|
| consumption for total coating line | 800–1 300 MJ/t (natural gas) |
| | 44–140 MJ/t (electrical) |
| | 20–44 MJ/t (hot water) |
| aluminising of sheet | 67 kWh/t (electricity) |
| | 273 kWh/t (gas) |
| lead-tin coating of sheet | 2.43 kWh/t (electricity) |
| | 1 490 MJ/t (gas) |

Energy consumption data for part C (BREF 6, 345–346, 350):

| | |
|---|---|
| degreasing | 0–44.6 kWh/t |
| pickling | 0–25 kWh/t |
| hot dipping | 180–1 000 kWh/t |

and many more where energy data are not available

Additionally, for the hot dipping process there is a short description of possible savings (BREF 6, 377–378, 384).

Enclosed galvanising pot → energy savings due to reduced surface heat loss from the galvanising bath.

Heat recovery from galvanising kettle heating → reduced fuel consumption. Energy reductions in the range of 15–45 kWh/t black steel.

### Best available techniques (BAT)

Principally there are two different types of techniques, those which have to be considered in the determination of BAT (techniques not yet considered BAT) and others which are already considered as BAT. For the ferrous metals processing industry these techniques are almost the same. Further, it is possible to divide the BAT into general techniques (primary measures) and more process specific ones.

### General BAT

The following measures can be considered as general techniques (primary measures) for the hot and cold forming part:

- general measures, e.g. regarding furnace design or operation and maintenance.

### Process specific BAT

*For part A, hot and cold forming: reheating and heat treatment furnaces*
- recovery of heat in the waste gas by feedstock preheating
- recovery of heat in the waste gas by regenerative or recuperative burner systems
- recovery of heat in the waste gas by waste heat boiler or evaporative skid cooling (where there is a need for steam) à energy savings 25–50 %
- limiting the air preheating temperature.

*Descaling*
- material tracking to reduce water and energy consumption.

For the others there are no BATs regarding energy aspects. Most of the energy related saving techniques are mentioned above.

### Specific aspects for energy saving and energy recovery measures

For some techniques (also BATs) energy savings have to be traded off against $NO_X$ emissions. Reductions in $SO_2$, $CO_2$ and CO have to be weighted against the disadvantage of potentially increased emissions of $NO_X$.

### Recommendation for the future

For the revision of this BREF, information on emissions, consumption levels and economics should be provided. Especially for quite a number of the techniques to be considered in the determination of BAT, there is a lack of information on these aspects at the moment. Of particular interest are figures on $NO_X$ emissions both for furnaces that use air preheating and those that do not. Such data would make it possible to do both a more thorough evaluation of the efficiency of reduction measures and a comparison of the advantages and disadvantages of energy savings versus $NO_X$ emissions.

## Glass manufacturing industry

### Importance of energy efficiency

Glassmaking is a very energy intensive activity and the choice of energy source, heating technique and heat recovery methods are central to the design of the furnace. The key environmental issues are emissions to the air and energy consumption.

### Most important processes/technologies related to energy efficiency

The melting operation is the central process in the glass manufacturing industry. Its environmental performance and energy efficiency is also affected by the choice of energy source, heating technique and heat-recovery methods. The three main energy sources for glassmaking are natural gas, fuel oil and electricity.

In general, the energy necessary for melting glass accounts for over 75 % of the total energy requirement of glass manufacturing. The theoretical energy requirements for the three most common glasses (soda-lime, borosilicate and crystal glass) for the melting process vary from 2.25 GJ/t to 2.68 GJ/t. The actual energy requirements in the various sectors vary widely from about 3.5 GJ/t to over 40 GJ/t. The amount of energy needed depends very heavily on the furnace design, scale and method of operation. However, most glass is produced in large furnaces and the energy requirement for melting is generally below 8 GJ/t (BREF 6, 72–75). For 1997 the energy consumption of the glass industry was approximately 265 GJ/t.

### Energy recovery or energy saving techniques for the main processes

The main melting techniques are listed below:

- regenerative furnaces
- recuperative furnaces
- oxy-fuel firing
- electric furnaces
- combined fossil fuel and electric melting
- discontinuous batch melters.

For the regenerative furnaces a heat recovery system is used, while for the oxy-fuel firing melting technique, energy savings are possible because it is not necessary to heat the atmospheric nitrogen to the temperature of the flames.

### Energy data and energy saving techniques for other processes

Generally, the glass industry can be subdivided into eight sectors based on the products manufactured. These products consist of container glass, flat glass, continuous filament glass fibre, domestic glass, special glass, mineral wool, ceramic fibre and frits. For each of these subsectors the melting process is dominant. However, there are a few other processes that should be mentioned.

| | |
|---|---|
| • the forming process | (2–5 %) |
| • annealing | (about 3 %) |
| • forehearths | (about 6 %) |
| • conversion | (about 11 %) |
| • factory heating | |
| • general services | |

The values show the range of the total energy consumption.

### Best available techniques (BAT)

For the glass manufacturing industry, only techniques used in the determination of BAT are mentioned. These techniques for reducing energy use are:

| | | |
|---|---|---|
| • melting technique and furnace design | | (about 15 %) |
| • combustion control and fuel choice | n.a. | |
| • cullet usage | | (2.5–3 %) |
| • waste heat boilers | n.a. | |
| • cullet/batch preheating | | (10–20 %) |

The values show the range of energy savings.

### Specific aspects for energy saving and energy recovery measures

There were no specific aspects concerning energy saving or energy recovery measures mentioned.

### Recommendation for the future

When the work is reviewed a more in-depth assessment of techniques to improve energy efficiency would be useful, taking into account more recently available information.

## Industrial cooling systems

### Importance of energy efficiency

Cooling is an essential part of many industrial processes and should be seen as an important element in the overall energy management system. The intention is to re-use superfluous heat of one process in other parts of the process or in different processes on site in order to minimise the need for discharge of waste heat into the environment.

### Most important processes/technologies related to energy efficiency

In this industrial sector it is easier to speak about cooling systems instead of processes. Usually it is a process that has to be cooled. There are eight cooling systems mentioned, whereas each system is principally characterised by the cooling medium, the main cooling principle, minimum approaches, the minimum achievable end temperature of the process medium, and the capacity of the industrial process. The environmental aspects are different for each of the industrial cooling systems. As far as energy consumption is concerned, the most important cooling system is closed circuit dry cooling. Most of the high energy consumption is used for driving the fans.

The energy requirement of industrial cooling systems can be considered as direct or an indirect consumption. Direct consumption is the use of energy to operate the cooling system. The major energy users are pumps and fans. The energy consumption of the production process is referred to as the indirect energy consumption caused by the cooling process.

The total (direct and indirect) energy consumption for a closed circuit cooling tower amounts to more than 34 kWe/MWth (BREF 8, 67–70).

### Energy recovery or energy saving techniques for the main processes

The energy saving and energy recovery techniques mentioned here do not refer just to the most important cooling system (closed circuit dry cooling), but rather give an overview of all applied cooling systems (BREF 8, executive summary, V). Basically it is possible to reduce the direct or indirect energy consumption. For the indirect energy reduction the following measures are available:

- select the cooling configuration with the lowest specific indirect energy consumption (in general once through systems)
- apply a design with small approaches; and
- reduce the resistance to heat exchange by proper maintenance of the cooling system.

The following measures are applicable to the reduction of direct energy consumption:

- use pumps and fans with higher efficiencies
- reduce resistance and pressure drops in the process by design of the cooling system and by application of low resistance drift eliminators and tower fill
- proper mechanical or chemical cleaning of surfaces to maintain low resistance in the process during operation.

### Energy data and energy saving techniques for other processes

All measures to reduce energy consumption have been discussed above for all cooling systems, together.

### Best available techniques (BAT)

Principally, the BATs are subdivided into general and process specific BATs.

### General BAT

The following are BATs in the design phase of a cooling system:

- to reduce resistance to water and airflow
- to apply high efficiency and low energy equipment
- to reduce the amount of energy demanding equipment
- to apply optimised cooling water treatment in once through systems and wet cooling towers to keep surfaces clean and avoid scaling, fouling and corrosion.

### Process specific BAT

The selection of wet or dry cooling or wet and dry cooling to meet process and site requirements should be aimed at the highest overall energy efficiency. To achieve a high overall energy efficiency when handling large amounts of low level heat (10–25ºC), it is BAT to use open once through systems for cooling. In a greenfield situation this may justify selection of a (coastal) site with reliable large amounts of cooling water available and with surface water with sufficient capacity to receive large amounts of discharged cooling water.

When cooling hazardous substances that pose a high risk to the environment, it is BAT to apply indirect cooling systems using a secondary cooling circuit (BREF 8, 125–126).

### Specific aspects for energy saving and energy recovery measures

It is acknowledged that the final BAT solution will be a site-specific solution.

## Summary of energy issues in the BREFs

All the analysed BREFs contain a considerable amount of information and data on energy. The most specific information is available for energy consumption within more or less all the sectors. As far as energy saving and energy recovery techniques are concerned, there is less information. In general, there is a need for more information regarding all the energy aspects (consumption, savings and recovery measures and va lues).

BATs are generally subdivided into general and process specific BATs. In a few cases, each process specific BAT within a industrial sector is shown in a table and described separately.

The purpose of the BAT chapter is thus to provide general indications regarding the emissions and consumption levels that might be considered as an appropriate reference point to assist in the determination of BAT-based permit conditions or for the establishment of general binding rules. In other words, environmental permit conditions should be based on BATs, and BREFs (which are not binding) should be taken into consideration as one important source of information on BAT.

A description of energy aspects found in each BREF follows (summary table in Section 5.14).

# Summary of energy efficiency (EE) aspects in the BREFs

| | Cement and lime<br>March 2000 | Iron and steel<br>March 2000 | Non-ferrous metals<br>May 2000 | Pulp and Paper<br>July 2000 | Chlor-alkali<br>October 2000 | Ferrous metals<br>October 2000 | Glass<br>October 2000 | Cooling systems<br>November 2000 |
|---|---|---|---|---|---|---|---|---|
| Importance of EE compared to other environmental issues | highly intensive emission air) | highly intensive (air emissions) | Important (air emissions) | High (water discharges) | Important (air / water emissions) | Important (air emissions) | very intensive (air emissions) | high |
| Which is the most important and energy intensive process/technology?<br>Is energy data available? | clinker burning, lime burning<br>yes, only for consumption | blast furnace<br>yes (good description) | Pyrometallurgical processes | depends on the plant evaporation/paper machine<br>yes, data available | mercury (amalgam)-technology<br>yes, only for consumption | heating and heat treatment furnace<br>yes (good description) | Melting<br>yes (good description) | closed circuit dry cooling dry air cooling<br>yes, only for consumption |
| Are energy recovery/savings techniques for this process mentioned? | not in detail, partly also considered as BAT | yes, a lot partly also considered as BAT | yes, consumption and recovery | consumption and recoveryes, techniques in general considered as BAT | yes, in terms of process selection | Selections, a lot partly already considered | yes, a lot | yes, but rarely |
| Is energy data for other processes (including techniques) available? | yes, in general for consumption | yes | yes, consumption + recovery | yes, consumption data available | yes, consumption data | yes (good) | yes, mainly for consumption | yes, consumption |
| General BAT available | yes (primary measures) | yes | yes | yes | yes (primary measures) | yes | yes (design phase) | yes (design phase) |
| Bat for specific processes | Yes, limited | Yes, Bats for all | yes | yes | Yes, limited | yes | Not mentioned as BAT (to consider in the determination of BAT) | yes |
| Energy data in BAT | Yes, only consumption (limited) | Yes, table for each BAT | yes | Yes, almost in every BAT | Yes, limited | Yes, data about consumption, saving recovery | Not concerning EE, only emission level | Yes, partly |
| Are energy recovery/savings measures site specific? | no | Not mentioned | yes | Yes, a few (CHP) | Yes, because of difficulties in storage + transport | Not mentioned | Not mentioned | Yes, but difficult to quantify |
| Are any recommendations for the next update mentioned? | survey of current tech-niques consumption is useful | n.a | more information about consumption data | more information on the assessment of energy efficient techniques | n.a. | provide more information on emission and consumption level | more techniques for EE improvement would be useful | n.a. |
| Special comments | energy costs = 30–50 % of total production costs associated BAT heat ba-lances value is 3 000 MJ/t clinker | There are many different kind of plants; each has different processes + techniques | Limited information about EE in BATs. General ok! | A lot of information concerning EE for each single process. A lot of energy recovery techniques are not considered as BATs yet. | Information about process conversion (technologies) and about legislation for some EU countries. Associated with BAT: <3 200 kWh per t of chlorine large consumption of electrical energy | Balance between EE and air pollution (for certain techniques)<br>Very detailed description of BATs | BATs are concentrated more on emissions<br>Melting process needs about 75 % of all energy usage | BATs are described but only a few have a lot of data<br>The final BAT solution will be a site-specific sol. Calculation model for energy conservation + saving is given |

# ANNEX 14 EUROPEAN ENERGY MIX

## Electricity

To create 1 GJ of electricity, the average fuel use and emissions released for the whole of Europe is:

| **Electricity** | **GJ** | **1** |
|---|---|---|
| | | |
| **Primary energy** | **GJ** | **2.57** |
| **Oil** | **kg** | **9.01** |
| **Gas** | **$m^3$** | **6.92** |
| **Coal** | **kg** | **15.7** |
| **Brown coal** | **kg** | **34.6** |
| | | |
| **$SO_2$** | **kg** | **0.10** |
| **$CO_2$** | **kg** | **117** |
| **$NO_2$** | **kg** | **0.16** |

| **European Mix** | |
|---|---|
| Oil | 9.6 % |
| Gas | 9.5 % |
| Hard coal | 18.3 % |
| Brown coal | 10.5 % |
| Nuclear | 36.0 % |

| **IFEU-Calculation** | | **Fuel oil** | **Electricity from oil firing** | **Natural gas** | **Electricity from gas** | **Hard coal** | **Electricity from coal** | **Brown coal** | **Electricity from brown coal** | **Nuclear power** |
|---|---|---|---|---|---|---|---|---|---|---|
| Current | GJ | | 1.00E+00 | | 1.00E+00 | | 1.00E+00 | | 1.00E+00 | 1.00E+00 |
| | | | | | | | | | | |
| Primary energy | GJ | 3.69E+00 | | 2.90E+00 | | 2.38E+00 | | 2.82E+00 | | 3.35E+00 |
| Oil | kg | 9.22E+01 | 7.88E+01 | | | | | | | 4.19E-01 |
| Gas | $m^3$ | | | 7.14E+01 | 5.33E+01 | | | | | 3.74E-01 |
| Coal | kg | | | | | 8.48E+01 | 8.19E+01 | | | 3.03E+00 |
| Brown coal | kg | | | | | | | 3.19E+02 | 3.12E+02 | |
| | | | | | | | | | | |
| $SO_2$ | kg | 6.44E-02 | 2.43E-01 | 3.24E-03 | 2.88E-03 | 5.05E-02 | 1.48E-01 | 3.73E-03 | 2.22E-01 | 3.22E-02 |
| $CO_2$ | kg | 1.26E+01 | 2.47E+02 | 1.46E+01 | 1.32E+02 | 1.06E+01 | 2.17E+02 | 7.84E+00 | 3.16E+02 | 6.27E+00 |
| $NO_2$ | kg | 3.46E-02 | 3.68E-01 | 7.79E-02 | 1.51E-01 | 4.11E-02 | 1.10E-01 | 6.30E-03 | 6.14E-01 | 1.43E-02 |

These average emission factors for electricity are derived from the ECOINVENT 1994 database.

## Steam

To produce steam with energy value of 1 GJ, the average fuel use and emissions released for the whole of Europe is:

| **Steam** | **GJ** | **1** |
|---|---|---|
| | | |
| **Primary energy** | **GJ** | **1.32** |
| **Oil** | **kg** | **12.96** |
| **Gas** | **$m^3$** | **10.46** |
| **Coal** | **kg** | **14.22** |
| | | |
| **$SO_2$** | **kg** | **0.54** |
| **$CO_2$** | **kg** | **97.20** |
| **$NO_2$** | **kg** | **0.18** |

| **European Mix** | |
|---|---|
| (estimated mix) | |
| Oil | 40.0 % |
| Gas | 30.0 % |
| Hard Coal | 30.0 % |

| | | **Fuel oil** | **Heat from oil firing** | **Natural gas** | **Heat from gas** | **Hard coal** | **Heat from coal** |
|---|---|---|---|---|---|---|---|
| Heat | GJ | | 1.00E+00 | | 1.00E+00 | | 1.00E+00 |
| | | | | | | | |
| Primary energy | GJ | 1.29E+00 | | 1.41E+00 | | 1.28E+00 | |
| Oil | kg | 3.24E+01 | 2.75E+01 | | | | |
| Gas | $m^3$ | | | 3.49E+01 | 2.81E+01 | | |
| Coal | kg | | | | | 4.74E+01 | 4.14E+01 |
| | | | | | | | |
| $SO_2$ | kg | 4.01E-02 | 9.95E-01 | 1.61E-02 | 5.75E-04 | 4.76E-02 | 3.70E-01 |
| $CO_2$ | kg | 6.51E+00 | 9.22E+01 | 7.16E+00 | 6.48E+01 | 5.82E+00 | 1.15E+02 |
| $NO_2$ | kg | 1.77E-02 | 1.78E-01 | 3.47E-02 | 4.47E-02 | 3.77E-02 | 2.17E-01 |
| | | | | | | | |
| **ECOINVENT** | | **Fuel oil** | **Heat from oil firing** | **Natural gas** | **Heat from gas** | **Hard coal** | **Heat from coal** |
| Heat | GJ | | 1.00E+00 | | 1.00E+00 | | 1.00E+00 |
| | | | | | | | |
| Primary Energy | GJ | 1.22E+00 | | 1.43E+00 | | 1.36E+00 | |
| Oil | kg | 3.06E+01 | 2.60E+01 | | | | |
| Gas | $m^3$ | | | 3.53E+01 | 3.00E+01 | | |
| Coal | kg | | | | | 5.21E+01 | 4.17E+01 |
| | | | | | | | |
| $SO_2$ | kg | 1.59E-02 | 1.41E+00 | 3.06E-02 | 6.47E-04 | 6.98E-02 | 6.29E-01 |
| $CO_2$ | kg | 4.24E-01 | 9.16E+01 | 7.29E+00 | 6.47E+01 | 6.36E+00 | 1.16E+02 |
| $NO_2$ | kg | 8.24E-04 | 1.88E-01 | 3.18E-02 | 2.35E-02 | 5.50E-02 | 2.50E-01 |
| | | | | | | | |
| **GEMIS** | | **Fuel oil** | **Heat from oil firing** | **Natural gas** | **Heat from gas** | **Hard coal** | **Heat from coal** |
| Heat | GJ | | 1.00E+00 | | 1.00E+00 | | 1.00E+00 |
| | | | | | | | |
| Primary Energy | GJ | 1.35E+00 | | 1.39E+00 | | 1.20E+00 | |
| Oil | kg | 3.42E+01 | 2.89E+01 | | | | |
| Gas | $m^3$ | | | 3.44E+01 | 2.63E+01 | | |
| Coal | kg | | | | | 4.27E+01 | 4.12E+01 |
| | | | | | | | |
| $SO_2$ | kg | 6.44E-02 | 5.78E-01 | 1.52E-03 | 5.03E-04 | 2.54E-02 | 1.11E-01 |
| $CO_2$ | kg | 1.26E+01 | 9.27E+01 | 7.02E+00 | 6.49E+01 | 5.28E+00 | 1.13E+02 |
| $NO_2$ | kg | 3.46E-02 | 1.69E-01 | 3.76E-02 | 6.59E-02 | 2.05E-02 | 1.83E-01 |

These average emissions factors for steam generation are derived as averages from the ECOINVENT and GEMIS databases.

# ANNEX 15 POWER FACTOR CORRECTION

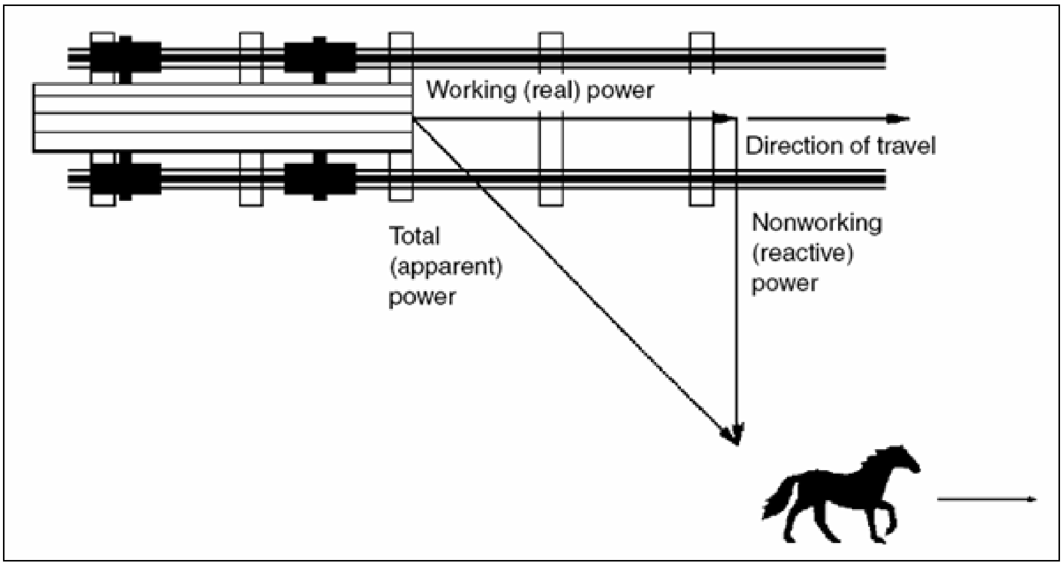

**Figure 8.16: Reactive and apparent power explanation**
**[123, US_DOE]**

To understand power factor, visualise a horse pulling a railway wagon along a track. Because the railway ties are uneven, the horse must pull the wagon from the side of the track. The horse is pulling the wagon at an angle to the direction of the wagon's travel. The power required to move the wagon down the track is the working (real) power. The effort of the horse is the total (apparent) power. Because of the angle of the horse's pull, not all of the horse's effort is used to move the wagon down the track. The wagon will not move sideways; therefore, the sideways pull of the horse is wasted effort or nonworking (reactive) power.

The angle of the horse's pull is related to power factor, which is defined as the ratio of real (working) power to apparent (total) power. If the horse is led closer to the centre of the track, the angle of side pull decreases and the real power approaches the value of the apparent power. Therefore, the ratio of real power to apparent power (the power factor) approaches 1. As the power factor approaches 1, the reactive (nonworking) power approaches 0.

**Reference:**
US DOE: Motor challenge programme, Fact sheet: Reducing Power Factor Cost
http://www1.eere.energy.gov/industry/bestpractices/pdfs/mc60405.pdf