



CARE+

Energy Efficiency Handbook
for Chemical SMEs

Energy Efficiency Best Practices

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About CARE+

The international chemical industry has for many years recognised that responsible stewardship of the environment is part of its overall operating duties. Cefic, the European Chemical Industry Council, has been a leading party in the industry's efforts through the Responsible Care Initiative. The CARE+ project is a complementary initiative to focus on the efficient use of energy in the vast number of small and medium sized chemical companies across Europe. CARE+ aims to

- Develop, test and offer an energy efficiency scheme for SMEs in the European chemical industry;
- Disseminate information about energy efficient technologies and energy management systems to SMEs (e.g. best practices);
- Through training and auditing demonstrate to SMEs energy efficiency reserves and cost-effectiveness of improved practices and technologies;
- Develop special investment schemes to facilitate implementation of identified energy efficiency measures in SMEs;
- Improve the sector's energy efficiency performance.

High energy prices and fierce global competition have stimulated energy efficiency in the chemical industry because energy constitutes an important part of the chemical industry's cost structure. Nevertheless, a potential for energy efficiency improvements remains, especially in SMEs, where energy consumption is not always seen as a major cost factor nor identified as a priority. Thus this project is designed to bridge the gap between the potential and the current practice.

CARE+ is funded and supported by the European Commission under the framework of "Intelligent Energy Europe".

These Energy Efficiency Best Practices, together with the Energy Efficiency Self Audit Guide are an essential part of CARE+, as they are the main support tools for SMEs to help improving their energy performance.

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Introduction: How to Work With The Energy Efficiency Best Practices

This Energy Efficiency Best Practices are part of an Energy Efficiency Handbook with two main parts, which can also be used as stand-alone documents.

- A Self Audit Guide to assist you undertaking energy audits and to assess your energy performance in a simple step-by-step approach.
- Best Practices focusing on the key areas for energy efficiency in chemical SMEs and describing “best in class” energy efficiency applications in the different areas.

Energy Efficiency Self Audit Guide

The Energy Self Audit Guide (SAG) provides small and medium sized companies in the European chemical industry with a step-by-step tool to check energy management performance, energy consumption and last but not least, energy efficiency. It is best used in combination with the Energy Efficiency Best Practices, as there you can find a lot of additional information that can be helpful. Nevertheless, the SAG can also be used as a stand alone tool.

Energy Efficiency Best Practices

The Best Practices focus on eight areas, which are considered to offer most energy saving opportunities for chemical SMEs. They give you a benchmark how your company would ideally do energy management in this area and show you the different improvement potentials, differentiating by good housekeeping measures, low or no cost, and issues where you could invest.

Due to the varied nature of the chemical industry, the focus of these Best Practices is on more generic energy efficiency measures rather than the very specific process improvement measures. This focus is important as significant energy savings are achievable through energy efficiency measures such as steam and compressed air zoning, monitoring and targeting, improved insulation and industrial building measures such as lighting and air movement controls.

The following areas are covered by the Best Practices:

Best Practice 1	How to Set Up and Work With an Energy Management Programme
Best Practice 2	How to Account and Analyse Your Energy Use
Best Practice 3	How to Set Up and Run an Energy Information System
Best Practice 4	How to Improve Your Steam Generation Performance
Best Practice 5	How to Reduce Energy Use in Your Compressed Air System
Best Practice 6	How to Reduce the Energy Use in Your Buildings
Best Practice 7	How to Improve Energy Efficiency With Your Motors And Drives
Best Practice 8	How to Improve Energy Efficiency in Your Process Plant

The first three Best Practices focus on energy management and measuring your energy consumption, as these two steps are the back bone of any energy efficiency activities. Best Practices 4 to 8 cover specific issues, which are most promising for energy savings.

The modular structure also allows you to add additional chapters of issues that are of interest for you. This is a flexible tool, so do not hesitate to use it in such a way.

Best Practice 1 How to Set Up and Work With an Energy Management Programme

BP 1 1. Why an Energy Management Programme?

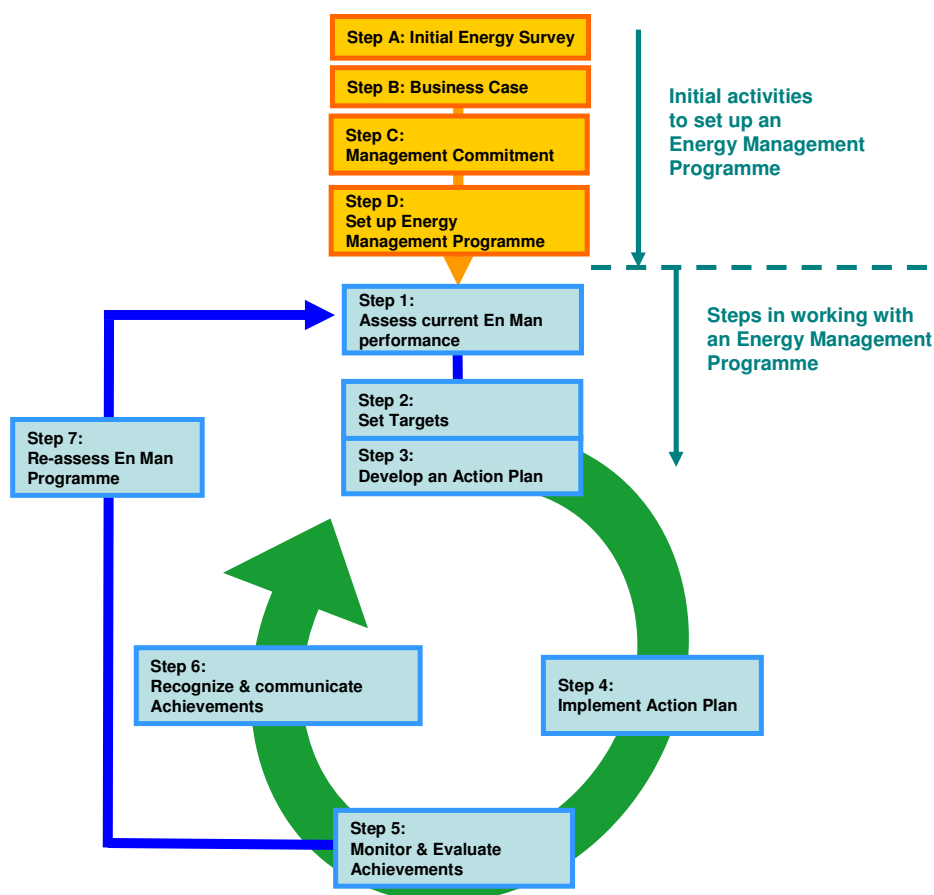
Energy management means a structural and continuous attention to energy use and energy costs, with the aim to improve the energy efficiency and reduce the costs. Therefore, it should be fully embedded in your company's business and an integral part of the daily management and operations. The best way to achieve that is to work with an energy management programme. This is why the first Best Practice is devoted to this issue.

Figure 1 gives an overview of energy management.

- Steps A, B, C, and D cover the set up phase of the management programme.
- The Steps 1 up to and including 7 describe how to work with the energy management programme.

Below each step is explained in more detail. Please note that in reality the transition from one step to the next in your specific energy management activities may be less rigid than might be suggested by this description.

FIGURE 1. STEPS IN ENERGY MANAGEMENT



Source: EPA EnergyStar

BP 1 2. How to Set Up an Energy Management Programme

BP 1 2.1. Introduction

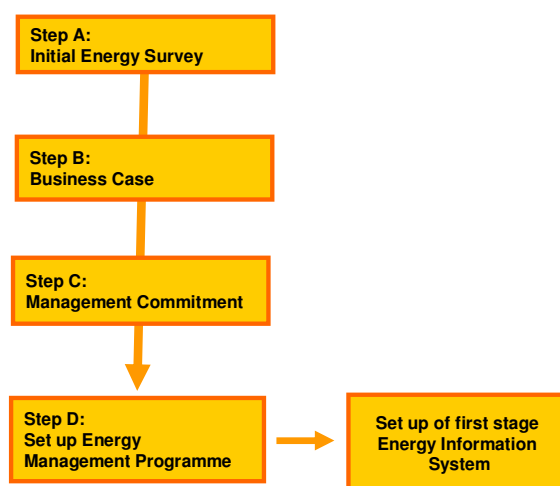
The common element in successful energy management programmes is commitment from the management and the key personnel that operate the plant, to manage energy use and energy costs in a structural continuous process. This can only be achieved with an appropriate energy management programme in place that is incorporated fully in the daily management and operations.

Thus, establishing an energy management programme starts with preparation activities to get the commitment from the highest management level in the organisation.

Figure 2 illustrates the different steps to set up an energy management programme. With reference to this Figure each step is described in the following sections.

FIGURE 2. SET UP OF AN ENERGY MANAGEMENT PROGRAMME

Activities to set up an Energy Management Programme



BP 1 2.2. Step A: Initial Energy Survey

Your preparation activities start with getting a good understanding and assessment of the current energy situation by conducting an initial energy survey. This initial energy survey can be very similar to the Energy Efficiency Audit which is outlined in the CARE+ Energy Efficiency Self Audit Guide. In this initial energy survey, you should investigate the following issues:

- The present level of energy management in the company.
- The present level of measuring, recording, and analysing energy data (you will find more information on this subject in the Best Practice 3 How to set up and run an energy information system).
- The present level of understanding and checking of energy bills.
- The main energy consuming equipment and processes.
- The effects of legislation and taxation on energy matters.
- The current energy data and the energy data over the past years (preferably at least three years).
- Production data from present and past years (three years as a minimum).

To express energy data in handy units it is advised that you use the SI units (Système International d'unités) with a few adaptations. For further information, see Best Practice 2 chapter 2.7 on energy conversion factors.

The Self Audit Guide provides checklists and data sheets to support you in executing the initial energy survey.

With the results, you can make a first estimate of possible energy savings and cost reductions. You can also define the starting points of an appropriate energy management programme for your company. As a guide, you should be able to track at least 80% of the total purchased energy input to where, when, and how it is being used in the factory. Moreover the initial survey should provide you with enough information to pass to the next step, preparing a business case.

The results will enable you to judge whether the energy measuring and recording equipment that is currently installed is adequate to start an advanced energy management programme (for details on the requirements regarding energy data acquisition, check Best Practice 3).

BP 1 2.3. Step B: Business Case

Based upon the information from the initial energy survey a business case for implementing an energy management programme can be developed to get management commitment and to initiate this programme.

In the business case, you should address the following issues:

- An estimate of the potential energy savings and (consequent) cost savings resulting from the energy management programme.
- The design of an energy management programme that is appropriate for your organisation.
- The organisational measures required for working with energy management.
- The evaluation tools and data infrastructure that is needed for a successful energy management programme.
- An estimate of the required investment and annual costs to implement and work with an energy management programme.
- An estimate of the economic returns of this investment programme.
- An estimate of the time line for implementation.
- The required management commitment and decisions for working with an energy management programme.

This business case is also a yardstick for the achievements once the energy management programme is in place. Please see the format provided in the Self Audit Guide for further information how such a business case could look like.

BP 1 2.4. Step C: Management Commitment

With the information in the business case, the management can make their decision on implementing the energy management programme.

This commitment should result in:

- A concrete energy policy statement and a clear energy savings strategy.
- The appointment of an energy manager, who is responsible for the functioning of the energy management system. In the next section under step D you find a broad description of the role and duties of the Energy Manager.
- The empowerment of the people who are involved in the implementation of energy management.
- The provision of the financial means to implement and execute the energy management system.
- The promotion of an energy efficient culture in the company.
- The decision to put reporting and assessment of energy efficiency achievements on the management team agenda on a regular basis.

The whole organisation should be informed of the decision to implement an energy management programme, the company's energy policy statement and its long-term strategy.

BP 1 2.5. Step D: Set up of the Energy Management Programme

The next step is to set up the energy management programme and put in place the necessary organisational structure. In this process the Energy Manager has a key role to play. The main activities and responsibilities of the energy manager include:

- Coordinating and directing the energy management programme;
- Promoting energy efficiency awareness in the organisation;
- Developing the energy policy;
- Assessing the potential benefits of energy management;
- Creating and leading self auditing teams;
- Assuring accountabilities and commitments from leading managers in the organisation;
- Developing the energy information system;
- Coordinating the identification of opportunities for improvement;
- Coordinating definition of performance indicators and target setting;
- Ensuring implementation of agreed upon improvements;
- Training key personnel;
- Monitoring and evaluating energy usage;
- Reporting to management;
- Obtaining and providing recognition for achievements;
- Re-assessing the energy management system.

TIP

Although it is important to have a clearly appointed energy management champion in the organisation, it should be avoided that energy management becomes a 'one-person' issue.

Additionally the following items must be organised and arranged by the Energy Manager for a successful energy management programme.

- In order to approach the energy savings opportunities systematically, the priorities in energy management should be identified.
- The scope of energy management should be agreed, i.e. organisation wide, facilities, processes or equipment.
- The roles and responsibilities of the key players in the organisation regarding energy management should be identified and agreed. Consider forming a small energy team of key players in the organisation that support the day-to-day decisions on energy management.
- An important action is to set up the first stage of an energy information system (see Best Practice 3) starting from the data gathering structure that is currently in use. Once the first stage is in place, the system can be improved step-by-step as part of the action plan (see Steps 3 and 4). The energy information system should provide accurate and consistent information to enable reliable management of energy use and of energy costs. It should also provide the information to analyse energy performance achievements.
- The timeline, detailed planning and the resources required to implement the energy management programme needs to be defined.

The results of the organisation structure should be documented in the overall energy management plan. You should communicate the energy policy and energy savings strategy to everyone in the organisation to raise awareness. Personnel should be informed, provided with relevant information and encouraged to contribute to energy performance improvements.

Once the organisational structure is in place you can start working with the energy management programme on target setting and implementation of energy efficiency measures.

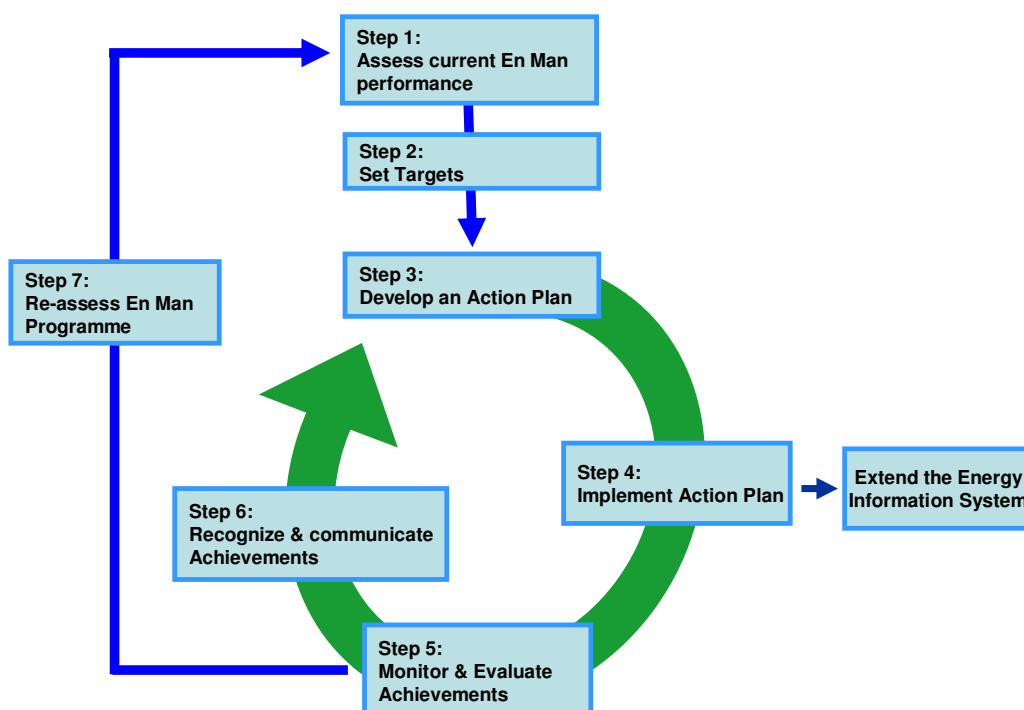
BP 1 3. How to Work With an Energy Management Programme

BP 1 3.1. Introduction

Once the set up of the energy management is done, you need to go further into the details, setting targets, develop an action plan and implement your activities. You also need to monitor and evaluate your energy efficiency activities, communicate your achievements and reassess your targets. This process reflects how to work with your energy management programme on a day to day basis.

How to work with an Energy Management Programme is reflected in Steps 1 to 7 in Figure 3 below in a circle which implies a continuous process that can be repeated as often as deemed necessary.

FIGURE 3. STEPS IN WORKING WITH AN ENERGY MANAGEMENT PROGRAMME



BP 1 3.2. Step 1: Assess Current Energy Management Performance

Your first step in working with energy management concentrates on getting a detailed knowledge about the current energy use and the development of meaningful energy performance indicators. A lot of information has already been gathered and put together when you set up the Energy Management Programme. Now you need to determine if you have to go a little bit more into detail. If you decide that you need to gather more information, then the process should be split in two parts:

- a data acquisition, and
- b defining energy performance indicators.

A) Data acquisition of current energy use and energy costs

The data acquisition should provide detailed information as to where, when, and how energy is being used in your factory. It should also provide information on the energy costs that are involved. Data acquisition should be done in the form of an energy audit. The Self Audit Guide provides guidance how to execute this energy audit and contains a detailed checklist of the items that you should investigate.

As far as possible, an energy information system should be the source of the information. The Best Practice 3 gives further information on how such an Energy Information System should look like. If you do not have such a system in place you could get information from other sources such as:

- Energy invoices and contracts.
- Design, commissioning and testing documents of the equipment and processes, as well as maintenance and operating manuals of equipment.

As a minimum, you should collect the information as indicated below. You should consider that the items 1 to 8 should have already been gathered when you did the initial energy survey. That is why now you have to check if there remain major blanks in the data availability that you have to fill. Items 8-14 are already more detailed and complex suggestions on what kind of data you could collect to refine your analysis of energy consumption and saving potential.

1. The present level of energy management in the company.
2. The present level of measuring, recording, and analysing energy data (you will find more information on this subject in the Best Practice 3 How to set up and run an energy information system).
3. The present level of understanding and checking of energy bills.
4. The main energy consuming equipment and processes.
5. The effects of legislation and taxation on energy matters.
6. The current energy data and the energy data over the past years (preferably at least three years).
7. Production data from present and past years (three years as a minimum).
8. All energy inputs (electricity, fuels, etc.) on a monthly basis.
9. All energy flows from energy conversions on site (self generated electricity, steam, hot water, etc.) on a monthly basis.
10. Energy consumption of main processes and equipment on a monthly basis.
11. Peak load energy consumption.
12. Monthly production data and operating hours of main processes and equipment
13. Monthly production data and operating hours of main utility equipment such air compressors, refrigeration units, cooling towers, etc.
14. Other factors influencing energy use, such as ambient temperatures.

B) Defining energy performance indicators

Monitoring and accounting for only absolute values of energy use and energy costs has limited value for an energy management programme. Energy use and costs should always be related to the main factors that influence this energy use. The following example provides an illustration.

TABLE 3. SPECIFIC ENERGY CONSUMPTION AS A PERFORMANCE INDICATOR

Year		2005	2006	2007	2008
Gas consumption	m ³ x1000/a	4990	4790	4690	5200
Production volume	tonnes/a	81000	75000	70000	85000
Specific gas consumption	m ³ /tonne prod	61.6	63.9	67.0	61.2

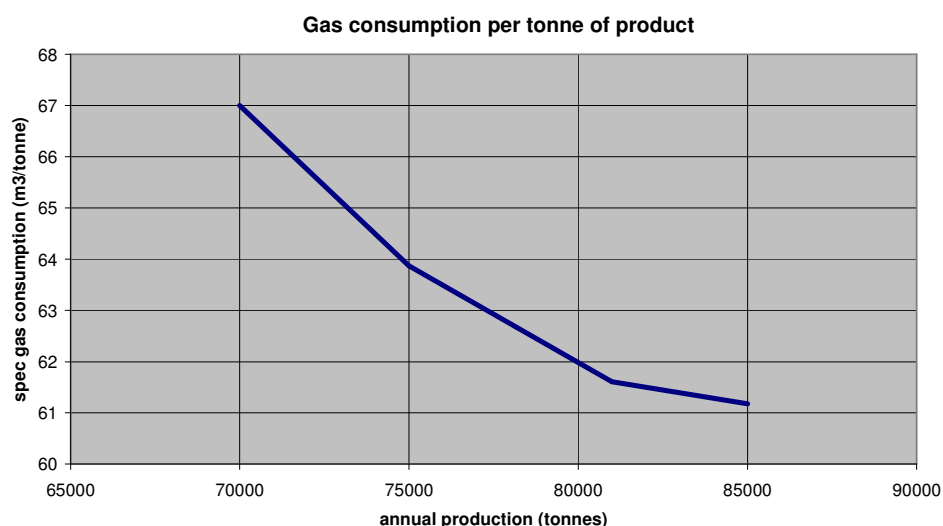
Table 3 gives the annual gas consumption over a period of 4 years of a typical medium sized chemical company with an annual energy bill in the range of €2 to 3 million, plus the total production volumes.

The annual gas consumption varies over the years, but without further information it is not clear what factors cause the variations. When the gas flow is related to the annual production, the specific energy consumption tells much more about changes in energy

consumption.

It can be seen that the specific gas consumption is lower with higher production volumes, so the company's energy efficiency increases with higher production volumes. Figure 4 shows the specific gas consumption in relation to the production volume.

FIGURE 4. RELATION BETWEEN SPECIFIC GAS CONSUMPTION AND PRODUCTION VOLUME



In an energy management programme, this information will be a trigger to investigate the reason why this change in efficiency is happening, and what can be done, for example, to improve the part-load energy efficiency. Therefore, in addition to the straightforward monitoring of energy consumption, you should also develop meaningful energy performance indicators. These should be in accordance with the scope and priorities of your energy management programme, with appropriate monitoring of your achievements in energy efficiency. This requires you to investigate what factors influence your energy consumption, and what the relationships are between various parts of your site.

The following set of performance indicators are often useful to work with:

- The overall site specific energy consumption (energy per unit of product or product mix) on a monthly basis.
- The specific energy consumption of major energy consumers on a monthly basis.
- Load patterns and peak load consumptions of major energy consumers.
- The energy consumption of heating, ventilation & air conditioning of buildings

You should also develop performance indicators that can be used by the operators in their daily operation of the plant. In most European countries weather conditions can have a big influence on energy consumption, especially for space heating and lighting. It is therefore important to normalise the results of performance indicators for weather conditions. How you can do this is explained in the Best Practice 2, which contains examples of performance indicators.

C) Performance trending

With performance indicators historical trending of energy performance can be undertaken and in-depth analyses of energy efficiency becomes possible. When starting for the first time, define a reference year and reference values for the performance indicators. With this historical reference point you can easily trend future improvements. Commonly the reference year is the first year you started with the energy management programme. The trending provides evidence as to how sustained your achievements are, and is useful to set realistic targets. Furthermore, it can be used for a more accurate estimate of future energy use in

relation to production forecasts.

BP 1 3.3. Step 2: Set Targets for Energy Savings

Setting targets should be done systematically. Starting points are the defined energy performance indicators and the information on energy use and energy costs, which has been gathered in the previous step. Targets must be measurable. They should be challenging but achievable. You should avoid unrealistic target setting in order not to lose the credibility of the programme.

To define workable targets you have to estimate the scope for energy savings. Take the following actions to achieve this:

- Estimate the potential for energy efficiency improvement in the different areas of your plant.
- Determine what technical improvements are possible with the present facilities and equipment. Consult the other Best Practices.
- Consider brainstorming with various departments and people in the organisation to identify in what form they can contribute to realising energy savings.
- Check whether the energy information system is adequate to providing the required information and performing the required analyses.

In the selection of targets, you should take into account the feasibility of reaching your goal. Therefore the investment requirements play an important role in the decision making process. Based on the financial cost you can distinguish between Good Housekeeping Measures, Pay-Back Targets and Strategic Targets. They are described in more details below.

A) Good Housekeeping Targets

These are related to the measures that concentrate on using and operating the existing facilities as efficiently as possible. They also include improvements in energy purchasing and checking energy bills. Good housekeeping options are easy to implement and are either free or at very low costs. When starting with energy management for the first time it is advisable to begin with good housekeeping measures.

For example, a target for applying good housekeeping at your site could be to achieve a 5 % reduction on overall energy consumption by checking losses in steam and condensate systems.

Table 4 below gives a number of examples of good housekeeping targets that concentrate on the following areas:

- The general maintenance practice of your plant;
- Operating the on site process installation;
- Steam generation and distribution;
- Heating, ventilation, air conditioning, and lighting buildings;
- Compressed air facilities;
- Refrigeration;
- Electric motors.

You will find more detailed information on these subjects in the various Best Practices.

It is important to prioritise the Good Housekeeping Targets, rather than to start with everything at once. Prioritisation can be on basis of one of the following:

- the biggest saving;
- the quickest results;
- the least disruption to the operation.

A list of possible measures for good housekeeping is given in Table 4.

TABLE 4. GOOD HOUSEKEEPING MEASURES

Area	Description
General	Regular maintenance is being performed on process equipment and energy and utility equipment and maintenance procedures are documented in the maintenance manuals
Processes	Process operating conditions and set points of equipment are checked regularly
	Checks as to how energy is being used are made regularly
	Load profiles are being monitored to investigate whether changes to more stable energy demand can be made
	Operation of batch processes have been optimised with energy demand and energy purchasing, and checks of the energy costs of the bigger incremental energy demands have been made
Steam	Boilers are being inspected and serviced regularly, at least annually. A correct preventive maintenance inspection regime should be executed. It depends on boiler type and fuel type what inspection and frequency is necessary for burners, burner management, flue-gas side, water-steam side."
	The boiler steam pressure is set at the minimum acceptable level for the steam distribution to the consumers. Peak steam demands (regular and irregular) have been carefully analysed and are avoided where possible
	Boiler efficiency is being trended on a monthly basis
	If more than one boiler operates in parallel then load management is done to optimise the overall efficiency
	Boiler stack losses are minimised by trimming the excess combustion air to the minimum required level (taking sufficient safety margin in excess O ₂ in the flue gases of the boiler). The combustion safeguarding system complies with the safety standards and is tested regularly to allow an optimal control of minimum excess combustion air
	The insulation of the boiler and piping and valves (removable insulation) is in a good condition
	Boiler water and return condensate chemical treatment is up to standard to avoid corrosion and scaling, and the boiler blow down rate is turned down to the minimum requirement
	De-aerator pressure is set at the minimum acceptable level for removing non-condensable gases from the boiler feed water
	The functioning of the de-aerator is checked regularly
	De-watering of the steam distribution system is installed properly and the functioning of steam traps is regularly checked
	Checks are made for steam leakages and any leaks repaired
	Regular inspections and repairs of piping insulation are being made
	Heat exchanger surfaces are regularly checked for scaling and fouling and cleaned when necessary

Compressed air	The system is being checked regularly for leaks and these are being repaired
	Unnecessary use of compressed air is avoided, and a checklist of users has been made
	Worn out air devices (such as spray nozzles) are replaced
	The pressure in the system is set at the minimum acceptable level taking into account the demand profile and the volume of storage vessels
	Boosting for small consumers requiring high pressure is investigated so that the overall system pressure can be reduced
	The capacity of pressure vessels is checked in relation to consumption pattern in order to optimise air compressor energy consumption
	Dry, oil free compressed air is being produced
	The dryers operate at the appropriate dew point set point for the required air quality
	Air pressure and volume are being measured
	Air compressor energy use is measured and related to air volume produced
	With multiple compressors operating the optimal load management has been investigated
	The utilisation of compressor cooling energy has been investigated
	The compressed air equipment is serviced regularly with regular replacement of filters
Refrigeration	Refrigeration units operate at the correct temperature set point
	The refrigeration system is regularly checked for leakages and any leaks repaired
	Refrigeration units are serviced annually
	Evaporators are de-iced regularly
	Condensers are kept clean
HVAC and Lighting	Insulation of pipework is kept in a good condition
	Heaters/boilers are being inspected and serviced regularly (at least annually)
	Regular maintenance on equipment is being done.
	For example, fans and air ducts are cleaned and filters are replaced regularly
	Evaporators and condensers of air conditioning units are clean and well maintained
	Where appropriate thermostat valves are installed on radiators
	Minimum heating requirements for individual areas in buildings have been determined and room thermostats work with the correct set points for climate control (heating, cooling, humidifying)
	Air conditioning units operate with the correct set points, for example simultaneous heating and cooling is excluded
	Energy conservation measure such as insulation, and outside sunlight shading, are being investigated
	Unnecessary heating elements are shut off
	Broken windows are being repaired and double glazed windows, with moist between panes are to be replaced.
	Lighting that is not needed is switched off
	Presence detection switches are used to switch on lights and off
	Replacing standard tungsten light bulbs with more efficient compact fluorescent bulbs has been done where appropriate
	High frequency fluorescent lighting is being considered where appropriate
	Exterior lighting is limited to hours of darkness
	Exterior lighting at unattended places is kept to a minimum, where appropriate presence detection switches are used to switch on these lights
	Partition of banks of lighting is being considered to install individual switches
Motor and Drives	Fans, pumps, etc are switched off when not needed
	Applying soft starters is being investigated for frequently starting equipment to avoid unnecessary peak demands
	Installation of high efficient electric motors is being investigated
	Frequency control on electric motors is being investigated to save energy at part load operation

B) Pay-back Targets

These are targets that concentrate on modifications, in for example processes or equipment, which can be realised with an acceptable economic rate of return.

They will require investment and implementation time and should be realised through normal investment procedures. The economic criterion that is often used for investments in this type of measures is a minimum rate of return on investment (IRR). Typically, companies will use an IRR of 15% (after tax) or more for energy investments. This is equivalent to a pay back of less than 4 years, however it does vary from company to company.

The Self Audit Guide helps you to prioritise the pay-back measures, but it focuses on the pay-back period only. In case you want to use the Internal Rate of Return as an additional measure, you find at the end of this Best Practice a short introduction how to calculate the IRR.

Pay-back targets could include:

- Improvement in boiler efficiency by installing economisers;
- The installation of energy efficient motors on key equipment.

These measures are normally implemented to achieve additional energy savings once the good housekeeping measures have been successfully put in place and have already brought the expected energy savings.

C) Strategic Targets

These targets involve strategic energy investments that are related to, for example license to operate issues (fuel switching, revamping of process equipment, replaying boilers because of emission standards, etc) or through major changes in energy consumption on the site. Strategic targets also play a role in investments decisions for new processes and process equipment. These measures normally require significant investment and might not fulfil the standard rate of return, but other reasons push for implementation.

This category could include:

- Improving overall efficiency by installing a condensate return system in the plant;
- The installation of Combined Heat and Power.

The classification with regards to costs helps to determine your targets. Remember to analyse and update the targets regularly (see Step 5).

BP 1 3.4. Step 3: Develop an Action Plan

With the targets defined the next step is to launch concrete actions to achieve these targets. Each target should be complemented with a list of actions you are planning to do to reach your target. You should document the actions in an action plan. This enables you to monitor and evaluate your activities at a later stage and make updates to the action plan.

The energy manager should coordinate the activity planning and organise the necessary meetings and discussions to decide on what actions are to be taken. This should then be documented in an action plan. The information in the Best Practice can be used to check present operations for improvement. In addition, you may wish to do some further reading, which provide valuable information on Best Available Technologies.

The action plan can contain the following information:

- The overall energy objectives and the targets to be achieved.
- The present energy consumption of the company.
- The reference values of the performance indicators.
- A list of all scheduled actions and activities that have been decided on to accomplish

- the action plan, with roles and responsibilities regarding its realisation.
- A brief description of each improvement action, with the related budgets and a time line for implementation.
 - The actions that are scheduled to improve energy purchasing.
 - The actions that are planned for training of personnel.
 - The studies and investigations that are scheduled regarding further technical and technological measures in the various sections of the plant.

The action plan should be approved by the management, and updated regularly. Usually, an annual update will be made but in the start-up period of the energy management programme more frequent updating may be appropriate.

BP 1 3.5. Step 4: Implement the Action Plan

With the action plan approved, the work on the various projects and actions can start. The energy manager should supervise the progress of scheduled actions and tasks and make regular progress reports. Furthermore, he should also coordinate the following activities:

- Promote energy efficiency practices and awareness in the organisation.
- Train key personnel in energy efficiency.
- Provide information on the energy performance of equipment and processes that are frequently used.
- Monitor the progress of the action plan on a monthly basis.
- Track energy data and performance indicators at the required intervals.
- Organise and assist with an energy purchasing policy.

BP 1 3.6. Step 5: Monitor and Evaluate Achievements

With the action plan in place, you should monitor and evaluate the progress regularly. Good practice is to do this at least once a year and in the early stages of the programme, it may be beneficial to do it more frequently.

Monitoring and Evaluation comprises the following steps:

- the regular analysis of the actual energy use in the plant, for example by making energy walk rounds,
- the evaluation of the results of energy actions and the functioning of the action plan, but also
- the formal reviewing, for instance once per year, of the achievements on the set targets.

The regular analysis of the actual energy use in the plant focuses on the daily operations and the good housekeeping measures. It will also provide early warning of deteriorating performance of (process) equipment and will provide supporting information to process operators for their daily operations. It will also monitor the achievements of good housekeeping measures. The energy manager should make regular energy walk rounds to check for good housekeeping of energy. In the Self Audit Guide, you will find a checklist that you can use for this activity.

The progress on the action plan, should be monitored regularly for instance on a monthly basis. In reviewing the action plan, the following points should be considered:

- Understand the effectiveness of the action plan (what worked well and what did not).
- Document best practices that can be shared throughout your organisation.
- Identify necessary corrective actions.
- Get feed back from the key personnel that are involved in the actions.

The formal reviewing of the energy efficiency achievements starts with an analysis of the measured results. Consult Best Practice 2 to know how you should do the analysis.

The analysis should provide at least the following results:

- Trends in the monthly energy consumption figures and purchased energy volumes.
- Trends in the development of the energy performance indicators.
- An understanding of the reasons for variable energy use and energy performance.
- Evidence of achievements in relation to targets.
- Information on the break down of energy use and energy costs over the major consumers.
- Verification of energy bills and energy purchasing.

The energy manager should issue a progress report containing all relevant information from the annual evaluation. The progress report will serve:

- To make decisions on future energy projects.
- To set the basis for new targets.
- To update the action plan.
- To make recommendations regarding improvements of the energy management programme.

BP 1 3.7. Step 6: Recognise and Communicate Achievements

Both providing and receiving recognition for accomplishments are of great importance to sustain the continuous process of energy management. Providing recognition within the organisation for achievements can be to individuals, to teams and management.

You can also use your energy management as a marketing tool. To get the external recognition that is deserved good external communication of accomplishments is essential.

At a certain stage, once the energy management programme has reached a reasonable level of sophistication, it may be worthwhile to seek recognition from qualified third parties.

BP 1 3.8. Step 7: Re-Assess the Energy Management Programme

Once per year the energy manager together with the energy team should re-assess the energy management programme. This re-assessment comprises a review and amendment of the energy policy and objectives, a review of the energy management procedures, analysing tools and the reporting formats, and, last but not least, the re-affirming of the management commitment as a basis for a new round of energy savings actions.

BP 1 4. Further information

Best Practice Example Energy Management Programme

This is the Energy Management Programme that one of the companies participating in CARE+ has developed, thanks to the project. This provides the company with the right organisational structure and long term planning for energy efficiency.

ENERGY MANAGEMENT PROGRAMME

1. Goals and scope of the Programme
 - Goal – no less than 6% energy savings over the next 3 years
 - Scope – all energy types used and all significant energy consumers
2. Organisational structure of the Energy Management System
 - Fixing role and functions of the Energy Manager
 - Fixing role and tasks of the other players of the Energy Management System

3. Action Plan

Goal: 6-7 % energy savings by the end of 2012:

Energy savings in 2010 – 1,5%;

Energy savings in 2011 – 2,0%;

Energy savings in 2012– 2,5%;

BP 1 4.1. Internal Rate of Return

In the Self Audit Guide we use as a general evaluation the pay back period. However, the rate of return is another important factor that you might want to take into consideration when prioritising the implementation of energy saving measures. It compares the profitability of different investment projects.

Generally speaking, the higher a project's internal rate of return, the more desirable it is to undertake the project. As such, IRR can be used to rank several prospective projects a firm is considering. Assuming all other factors are equal among the various projects, the project with the highest IRR would probably be considered the best and undertaken first.

What you do is analyzing the cash flows over time. Therefore you need the sequence of cash flows, including the initial investment.

This can be the following values

	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8
Initial Investment	-3000							
Savings	650	650	650	650	650	650	650	650
Total Cash Flow	-2350	550	550	550	550	550	550	550

Internal rate of return **14.1%**

The formula to be used is the following:

Given the (period, cash flow) pairs (n, C_n) where n is a positive integer, the total number of periods N , and the net present value NPV, the internal rate of return is given by r in:

$$NPV = \sum_{n=0}^N \frac{C_n}{(1+r)^n} = 0$$

Excel offers you a simple tool to calculate the rate of return, you just need to provide the data as indicated above and use the function “IRR” from the financial calculation tools.

BP 1 4.2. Additional reading

1. Energy Management Fact Sheet, Carbon Trust publication GIL136
www.carbontrust.co.uk
2. Practical energy management, Carbon Trust publication CTV023,
www.carbontrust.co.uk
3. Guideline for energy management, EPA EnergyStar publication,
www.energystar.gov/index
4. Step by step guidance for the implementation of energy management, handbook
Bess Project,
www.bess-project.info
5. The European standard EN 16001.2009 – Energy Management Systems –
requirements with guidance for use
<http://www.cen.eu>

Best Practice 2 How to Account and Analyse Your Energy Use

BP 2 1. Introduction

Understanding where and how energy is being used is essential for managing your energy use. As described in the SAG, this should be achieved by means of a regular analysis of your energy use and energy costs. The analysis will also provide evidence of what savings have been realised and how sustained they are.

In order to be able to analyse your energy information you should work with an adequate form of energy data accounting. This part of the Best Practices provides a structure for energy accounting.

In the analysis of your energy use you should not only look to straightforward energy consumption but also to the relationship with influencing factors. Chapter 8 of this Best Practice describes a number of relationships that you can consider to use.

BP 2 2. What Information Should be Available?

The energy data that should be measured and recorded at a minimum are:

- All monthly energy input flows and qualities (electricity, fuels, etc.). Your supplier might be the only source for this information or part of this information. Check with your supplier how he can provide you with the required data.
- The monthly energy invoices from suppliers.
- All monthly on site energy conversion quantities (self generated electricity, steam, hot water, etc.).
- The monthly energy consumption of main processes and equipment.
- Peak load consumption data over the appropriate time interval. To measure peak load energy consumption, for example electricity use, the energy consumption must be measured over shorter time intervals, for example ½ hourly readings. Check with your suppliers whether they presently retrieve these data from the meters. If that is not the case, consider the use of temporary portable meters to get data on peak loads (see Best Practice 3).
- Monthly production data and operating hours of main processes and process equipment, and main utility equipment such as air compressors, refrigerating units, cooling towers, etc.
- Data on other influencing factors that affect energy use, such as ambient temperatures.

BP 2 3. Understand What Is on Your Energy Bills

Your energy invoices and your energy contracts, in particular for electricity and gas, contain important information for analysing your energy use.

Natural gas, for example, is measured by the volume passing through the meter. So in order to calculate the energy input you also need to know the gas quality. Your supplier should specify the quality of the fuel.

Particularly for natural gas, be aware of the difference between Higher Heating Value (or Gross Calorific Value) and Lower Heating Value (or Net Calorific Value), the LHV is about 10% lower than the HHV. Check whether that is specified on your bill or otherwise ask your supplier for this information. The same applies for other fuels such as fuel oil or coal.

Check what time interval is used on your gas bill (daily, monthly, or quarterly consumption). Furthermore, the bill should specify the maximum hourly quantity that you have taken in that month. You can use this information to optimise your peak demand and consequential capacity costs. If your energy information system is able to receive on line data, discuss with your supplier whether you can receive his meter readings.

Electricity quantity is measured by the number of kilowatt hours. The invoice normally also specifies the peak demand in that month and the reactive power (related to the power factor) that you have taken. It is also important to understand the difference between kW, kVA, and kVAR on your bill. Understand the tariffs that are used by the supplier; and check whether they are correct. Check with your supplier the time interval that is used for the meter readings. Preferably this should be ½ hour readings. Discuss with your supplier whether these readings can be made available to you, because this will enable analysis of peak loads in your demand.

Check with the natural gas and electricity quantities whether you have kept your demand within the contractual limits in order to avoid penalties.

BP 2 4. Higher Heating Value (HHV) and Lower Heating Value (LHV)

The energy content of fuels can be expressed in the Higher Heating Value (also called Gross Calorific Value) or the Lower Heating Value (Net Calorific Value), the first also takes into account the condensation heat formed from H₂O when burning hydrocarbons. Normally, the heat content of fuels is specified by suppliers in LHV, except for natural gas. The energy content of natural gas is commonly specified by the supplier in MWh HHV. The difference for natural gas is approximately 10% (1 MWh HHV = 0.9 MWh LHV). In addition, market prices are given in €/MWh HHV, whilst the meter reading is in Nm³ (i.e. flow measurement with pressure and temperature correction to Normal m³).

It is advised that you make all energy calculations on basis of LHV. Table 5 provides the required conversion factors for natural gas.

TABLE 5. HHV TO LHV CONVERSION FACTORS

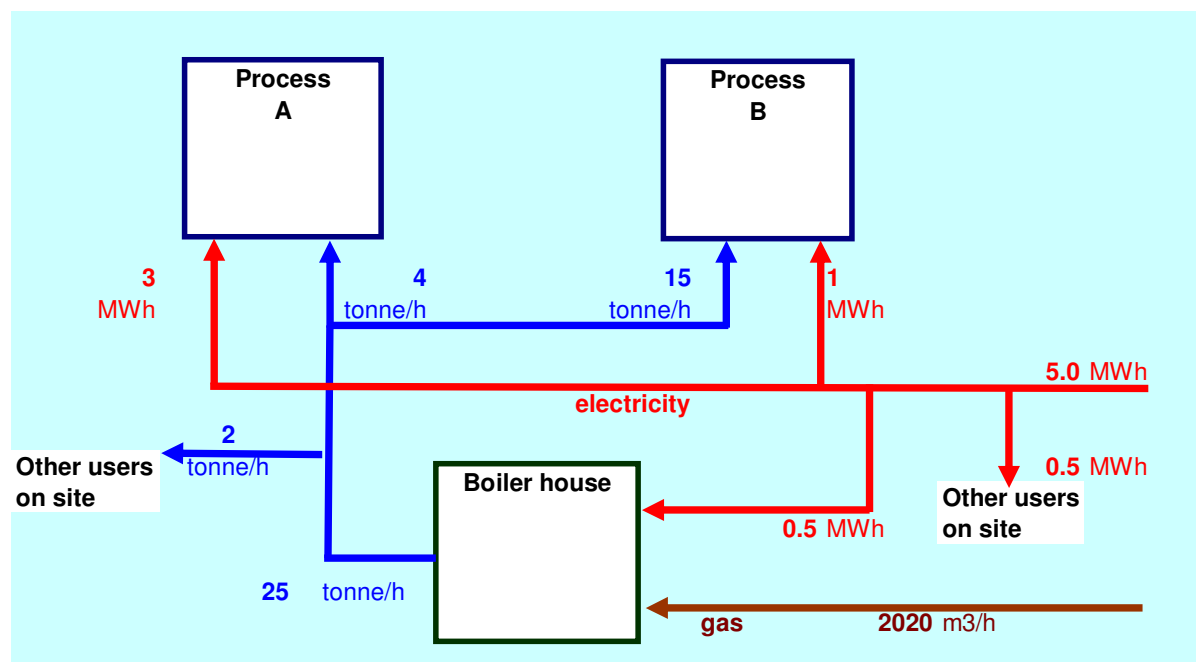
From HHV	To LHV
1 MWh	0.9 MWh
	3.24 GJ
1 GJ	0.9 GJ

BP 2 5. Accounting Energy Use

In setting up your accounting system you should select appropriate units in which to express energy. It is advisable to use the SI units, i.e. Joule for energy. If you want to know more details on the SI units, Chapter 9.1. of this best Practice recommends additional reading on this item.

As a basis for all your analyses, as a minimum you should make monthly energy balances of energy use on your site. The balances should indicate: all purchased energy and where it is being used, and all on site energy conversions and where it is being used. This will enable you to identify and trend the major energy consumers of your plant. You will find a complete set of energy accounting data sheets in the Self Audit Guide.

Figure 5 gives an example of the monthly energy accounting of a medium sized chemical company showing a simplified flow scheme for the plant that has been analysed. Based on the monthly data and the hours in use, you can calculate the flows per hour. If you are not able to do this further breakdown, you can also use monthly data.

FIGURE 5. PLANT FLOW SCHEME


The energy accounting is illustrated in the next suite of tables. The first energy accounting concerns financial data and the monthly energy purchases and where they are used in the plant (Tables 6 and 7). However, please be aware that data is not related to Figure 5.

TABLE 6. MONTHLY FINANCIAL DATA -

Monthly Financial Data								
	Total Production	Energy Costs	Total Production Costs	Sales Revenues	Gross Profit	Return on Sales	Energy Cost / Total Costs	Energy Costs / Tonne of Production
	Tonnes	€	€	€	€	%	%	€
January	27,000	€ 140,912	€ 1,160,000	€ 1,000,000	-€ 160,000	-16.0%	12.1%	€ 5.22
February	28,000	€ 141,224	€ 1,130,000	€ 1,750,000	€ 620,000	35.4%	12.5%	€ 5.04
March	28,000	€ 140,424	€ 1,140,000	€ 1,500,000	€ 360,000	24.0%	12.3%	€ 5.02
April	28,000	€ 148,102	€ 1,190,000	€ 1,500,000	€ 310,000	20.7%	12.4%	€ 5.29
May	27,000	€ 147,900	€ 1,090,000	€ 1,000,000	-€ 90,000	-9.0%	13.6%	€ 5.48
June	25,000	€ 153,071	€ 1,000,000	€ 1,000,000	€ -	0.0%	15.3%	€ 6.12
July	12,000	€ 128,255	€ 750,000	€ 900,000	€ 150,000	16.7%	17.1%	€ 10.69
August	20,000	€ 130,546	€ 1,000,000	€ 1,500,000	€ 500,000	33.3%	13.1%	€ 6.53
September	25,000	€ 134,016	€ 1,100,000	€ 2,000,000	€ 900,000	45.0%	12.2%	€ 5.36
October	26,000	€ 134,576	€ 1,050,000	€ 1,500,000	€ 450,000	30.0%	12.8%	€ 5.18
November	27,000	€ 140,736	€ 1,150,000	€ 1,000,000	-€ 150,000	-15.0%	12.2%	€ 5.21
December	20,000	€ 125,645	€ 900,000	€ 750,000	-€ 150,000	-20.0%	14.0%	€ 6.28
Total	293,000	€ 1,665,407	€ 12,660,000	€ 15,400,000	€ 2,740,000	17.8%	13.2%	€ 5.68

Source: CARE+ SAG Excel Sheets

TABLE 7. MONTHLY ACCOUNT OF ENERGY PURCHASES - ELECTRICITY

Monthly Purchased Energy Quantities						
	Electricity					
	Quantity (MWh)	Peak Demand (MWe)	Unit Cost (Euro/ MWh)	Total Other Charges (Euro)	Total Cost (Euro)	CO2 Emissions (Tonnes)
January	402	0.94	€ 42.00	€ 1,500	€ 18,384	251.99
February	410	0.94	€ 42.00	€ 1,500	€ 18,720	257.01
March	408	0.95	€ 40.00	€ 1,600	€ 17,920	255.75
April	399	0.90	€ 48.00	€ 1,400	€ 20,552	250.11
May	380	0.90	€ 50.00	€ 1,400	€ 20,400	238.20
June	382	0.90	€ 45.00	€ 1,400	€ 18,590	239.46
July	225	0.88	€ 43.00	€ 1,350	€ 11,025	141.04
August	350	0.89	€ 48.00	€ 1,350	€ 18,150	219.40
September	388	0.91	€ 52.00	€ 1,400	€ 21,576	243.22
October	396	0.93	€ 52.00	€ 1,500	€ 22,092	248.23
November	410	0.94	€ 53.00	€ 1,500	€ 23,230	257.01
December	325	0.95	€ 56.00	€ 1,600	€ 19,800	203.73
Total	4475		€ 47.58	€ 17,500	€ 230,439	2805.15

Source: CARE+ SAG Excel Sheets

The next step is to include all on site converted energy, such as heat or hot water. Table 8 illustrates the amount of energy converted.

TABLE 8. ENERGY CONVERSION VOLUMES - EXAMPLE OF STEAM BOILER

	STEAM BOILER 2									
	Steam	Calculated Steam (if not specified)	Enthalpy	Heat		Fuel Quantity		Boiler Efficiency	Total Steam Cost	Steam Cost per Tonne
	Tonnes	Tonnes	MJ	MWh		Nm3	MWh	%	€	€
January		3,577	9,178,333	2,549.54		300,000	3,109.19	82.00%	€ 70,250	N/A
February		2,981	7,648,611	2,124.61		250,000	2,590.99	82.00%	€ 58,542	N/A
March		3,577	9,178,333	2,549.54		300,000	3,109.19	82.00%	€ 70,250	N/A
April		2,981	7,648,611	2,124.61		250,000	2,590.99	82.00%	€ 58,542	N/A
May		2,981	7,648,611	2,124.61		250,000	2,590.99	82.00%	€ 58,542	N/A
June		2,981	7,648,611	2,124.61		250,000	2,590.99	82.00%	€ 58,542	N/A
July		1,192	3,059,444	849.85		100,000	1,036.40	82.00%	€ 23,417	N/A
August		2,385	6,118,889	1,699.69		200,000	2,072.79	82.00%	€ 46,833	N/A
September		3,577	9,178,333	2,549.54		300,000	3,109.19	82.00%	€ 70,250	N/A
October		2,981	7,648,611	2,124.61		250,000	2,590.99	82.00%	€ 58,542	N/A
November		2,981	7,648,611	2,124.61		250,000	2,590.99	82.00%	€ 58,542	N/A
December		2,981	7,648,611	2,124.61		250,000	2,590.99	82.00%	€ 58,542	N/A
Total	0	35,177	90,253,612	25,070.45		2,950,000	30,573.72	82.00%	€ 690,792	N/A

Source: CARE+ SAG Excel Sheets

The next step is to put all purchased and on site converted energy together, including the production data, and other influencing factors (see Table 9). The CARE+ Energy Efficiency Self Audit offers you Excel sheets which help you to go through this entire process.

TABLE 9. MONTHLY ACCOUNTING OF ON-SITE ENERGY USE

Data sheet		Monthly accounting of on site energy use												
Year	2009													
Month	Febr													
Production:		Unit												
	Product A	15000	tonnes											
	Product B	2000	tonnes											
Ambient conditions														
	Degree days	250												
	Average ambient temp	3	°C											
	Total use	Unit	Unit 1		Unit 2		Unit 3		Unit 4		Balance In/Out %			
			In	Out	In	Out	In	Out	In	Out				
Production		e.g tonnes		15000		2000								
Electricity	2000	MWh el	500	0	600	0	200	0	500	0	200	10.0		
Natural gas	1100	Nm ³ x 1000	0	0	380	0	720	0	0	0	0	0.0		
	39270	GJ LHV	0	0	13566	0	25704	0	0	0	0	0.0		
Gas Oil	0	litres	0		0		0		0		0	0.0		
	0	GJ LHV	0.0		0.0		0.0		0.0		0	0.0		
Steam	14000	tonnes	7000		5000			14000	1000		1000	7.1		
	35000	GJ sec ²⁾	17500		12500			35000	2500		2500	7.1		
Condensate return	8000	m ³		6000		2000	8000			0	0	0.0		
	3600	GJ sec ³⁾		2700		900	3600			0	0	0.0		

The energy quantities are specified in both the measured units (i.e. tonnes, Nm³, etc.) and in GJ energy content. In these forms the different energy quantities cannot simply be added because their quality is different. A distinction is made between:

- primary energy, these are all fuels, and
- secondary energy, these are all useful energy provided by the converted energy from the fuels. To make secondary energy forms comparable they can be converted into equivalent primary energy. Section 2.6 of this Best Practice explains how this can be done.

The last step in the accounting is to make an overview of all energy quantities, expressed in equivalent primary energy. This is shown in Table 10.

TABLE 10. PRIMARY ENERGY ACCOUNTING

Data sheet													Monthly on site energy use as primary energy equivalents (Unit = GJ LHV)														
Year		2009																									
Month		Febr																									
Production:		Unit																									
Product A		15000																									
Product B		2000																									
Ambient conditions																											
Degree days		250																									
Average ambient temp		3 °C																									
		Total		Site	Total use	Unit 1		Unit 2		Unit 3		Unit 4		Remark													
		In		Out		In	Out	In	Out	In	Out	In	Out														
Production (e.g. tonnes)							In	Out		In	Out		In	Out													
Electricity		18000			18000	4500	0	15000	5400	0	2000	1800	0	4500	0		1)										
Natural gas		39270			39270	0	0	0	13566	0	0	25704	0	0	0												
Gas Oil		0			0	0			0			0		0													
Steam					38889	19444			13889				38889	2778			2)										
Condensate return					4000		3000			1000		4000			0		2)										
Total		57270				23944	3000		32855	1000		31504	38889	7278	0												

Remarks: 1) and 2) see section 2.6

BP 2 6. Standardising Different Forms of Energy

As shown earlier, energy analysis often deals with different energy forms (electricity, natural gas, steam, hot water, etc.). They can be categorised into two groups:

- the different fuels as primary energy forms,
- the different useful energies, such as electricity and heat, as secondary energy forms.

These energy forms are not all directly comparable, because their quality is different, and therefore also their pricing. For example, 1 kWh of electricity may cost €0.10 per kWh, and 1 kWh of steam may cost €0.02 per kWh of steam. The main reason for this difference is the amount of primary energy input that is required to produce the different forms of secondary energy, such as electricity and steam.

In the energy analysis you should take this difference into account by converting the secondary energy forms, like electricity and heat, into equivalent primary energy flows. The conversion factor is a standardised efficiency with which the particular secondary energy is supposed to be generated: so standard power station efficiency for electricity and standard boiler efficiency for steam. Once this is done the energy flows are comparable and can be added together in calculating for example the energy performance indicators.

Figure 5 in chapter 5 shows how this works. The example gives the energy input for a plant with a central boiler house and two main process areas. The basic scheme shows the primary intake energy quantities and the distribution of the secondary useful energy quantities. The energy flows in their original form are presented in summary form in Table 11.

TABLE 11. ENERGY FLOWS PER HOUR

Measured energy flows per hour:						
Energy Form	Unit	Purchase	Boiler house		Process A	Process B
			in	out	in	in
Gas	Nm ³ /h	2020	2020			
Electricity	MWh	5.0	0.5		3	1
Steam	tonnes/h			22	4	15
						2

In these units the energy quantities are not comparable, and the steam flow is still in tonnes/h. To calculate the heat content of steam, condensate and hot water flows you have to know the temperature and pressure of these flows. With this information you can find the enthalpy value (as kJ/kg = MJ/tonne). These data can be found in Properties of Water and Steam in SI-Units, by Ernst Schmidt, Springer-Verlag. The CARE+ Self Audit Guide Excel tables also help you do this calculation.

By knowing the enthalpy values the heat content of the steam quantity can be calculated in GJ steam (in this example the enthalpy of 1 tonne of steam is 2800 MJ). Instead of GJ you can also use MWh to express the heat content in, as long as you do that consistently for all energies.

Table 12 gives the energy quantity in GJ (primary and secondary) related to each energy flow from Table 11.

TABLE 12. ENERGY FLOWS IN COMMON UNITS¹

Energy quantity per hour:							
Energy Form		Purchase	Boiler house		Process A	Process B	Other users
			in	out	in	in	in
Gas	Nm ³ /h	2020	2020				
Gas	GJ/h	72.1	72.1				
Electricity	MWh	5.0	0.5		3.0	1.0	0.5
	GJ el/h	18.0	1.8		10.8	3.6	1.8
Steam	tonnes/h			22	4	15	2
	GJ steam/t	0.0	73.9	61.6	11.2	42.0	5.6

Table 13 gives all energy quantity as equivalent primary energy in GJ. Fuels are already primary energy flows; the only conversion needed is from Nm³ to GJ energy. In addition electricity is converted to primary energy in GJ, assuming 40% efficiency. Steam is converted to primary energy in GJ, assuming 90% efficiency (see table 14 for conversion factors).

TABLE 13. ENERGY FLOWS IN PRIMARY UNITS

Energy quantities per hour in equivalent primary:							
Energy Form		Purchase	Boiler house		Process A	Process B	Other users
			in	out	in	in	in
Gas	GJprim/h	72.1	72.1				
Electricity	GJprim/h	45.0	4.5		27.0	9.0	4.5
Steam	GJprim/h			68.4	12.4	46.7	6.2
Total	GJprim/h	117.1	76.6	68.4	39.4	55.7	10.7

The end result is that the energy flows as primary energy now can be added and be used for target setting and the analysis of your energy use. The conversion factors that have been used to transfer secondary energy into primary energy are summarised in Table 14.

TABLE 14. CONVERSION FACTORS
Calculation formula's to convert electricity and heat into primary energy as GJ LHV

	From Secondary form		Into Primary form
Electricity 1)	kWh el		MJ prim
	1	x 9	9
Steam 2)	MJ steam		MJ prim
	1	x 1.1	1.1
Condensate 2)	MJ cond		MJ prim
	1	x 1.1	1.1
Hot water 2)	MJ hot w		MJ prim
	1	x 1.1	1.1

Formula:

1) For electricity a standard efficiency of 40 % is used:

$$1 \text{ kWh el} = 3.6 \text{ MJ el} = 3.6/0.4 = 9 \text{ MJ primary energy}$$

2) For steam, condensate and hot water a standard efficiency of 90 % is used:

$$1 \text{ GJ steam} = 1/0.9 = 1.1 \text{ GJ primary energy}$$

¹ For natural gas the energy content in MJ per Nm³ depends on the gas quality. Ask your supplier for a regular specification of the heat content of the fuel. In this example the enthalpy of steam is 2800 MJ/tonne.

This conversion can easily be implemented in the analysis tools of the energy information system. For practical purposes it is recommended to use two conversion efficiencies:

- For electricity: 40 % efficiency
- For heat (steam, hot water, etc.): 90 % efficiency.

BP 2 7. Energy Conversion Factors

Energy is expressed in many different forms. For a convenient energy management programme it is advisable to work as much as possible on basis of the SI units (Système International d'unités), with a few adaptations.

- For pressure "bar" is a more convenient unit than "pascal" and
- For temperature "degree Celcius" is used instead of "degree Kelvin".

BP 2 7.1. Unit Conversion Factor

The basic unit for energy is Joule (J). 1 J = 1 Newton.m. In order to avoid unworkably large numbers normally a prefix is used with 'J'. The practical minimum level is kJ (1000 J).

Symbol	Prefix	Dimension
PJ	peta	10^{15} J 10^{12} kJ
TJ	tera	10^{12} J 10^9 kJ
GJ	giga	10^9 J 10^6 kJ
MJ	mega	10^6 J 10^3 kJ
kJ	kilo	10^3 J

Most common energy conversion factors:

From	To	Conversion
kcal	kJ	4.19
Btu	kJ	1.055
Therm	MJ	105.5
kWh	kJ	3600

Heat content of fuels:

The table below gives the typical heat content of different fuels. They can vary depending on the supplier and the origin, so you should check on your energy bill or consult your supplier about the specifics of your purchases.

Fuel	Unit ¹⁾	Energy content	Remarks
Natural gas	kJ/Nm ³ ²⁾	35670	
Gas/diesel oil	MJ/tonnes	45500	littres/tonne: 1155
LSFO ³⁾	MJ/tonnes	43600	littres/tonne: 1014
Coal	MJ/tonnes	26900	

notes:

1) all heat content figures as LHV

2) Nm³ = standardised volume at 25 C

3) Low Sulphur Fuel Oil

Understand in what form energy is being delivered and charged on the energy bills. The table below lists the most common energy forms and their dimensions.

Energy form	Dimension	Remarks
Electricity	MWh or kWh	
Natural gas	Nm ³ or MWh HHV	1)
Heat	MWh or GJ LHV	2)
Steam	Tonne or MWh or GJ LHV	3)
Oil	M ³	
Coal	Tonne	

Notes:

1. HHV stands for Higher Heating Value. The energy content of fuels can be expressed in higher heating value and lower heating value. For natural gas, the HHV is approximately 10 % higher than the LHV.

2. Heat is normally expressed in MWh or GJ based on LHV; 1 MWh = 3.6 GJ

3. Steam can be expressed in tonnes or in the heat content (MWh or GJ). If it is specified in tonnes, the pressure and temperature must be known also in order to calculate the heat content.

BP 2 8. What should be Analysed and How Should it be Done?

BP 2 8.1. Introduction

The previous chapters have provided you with the basis to collect and prepare the necessary information to do an analysis. This chapter will focus on what you can do with this information and what exactly should be analysed.

Your analysis in the various steps in the programme should provide at least the following results:

- Trends in the monthly and annual energy consumption figures and purchased energy volumes.
- Trends in the development of the energy performance indicators.
- An understanding of the reasons for variable energy use and energy performance.
- Evidence of achievements in relation to the set targets.
- Information on break down of energy use and energy costs over the major consumers.
- Verification of energy bills and energy purchasing.
- Setting targets for energy reductions.

This section describes a number of performance indicators that you can consider to use in your analysis. Your energy information system should be able to make all required calculations and to provide the analysis information.

The following indicators are described in more detail

- Specific Energy Consumption per Unit of End Product or Product Mix
- Specific Energy Consumption Related to the Reference Value in the Reference Year
- Load Profiles to Identify Peak Loads
- Energy Consumption of Buildings in Relation to Outside Temperature

Many other indicators are possible, but nevertheless the selection of indicators gives you a good idea of what can be done.

BP 2 8.2. Specific Energy Consumption per Unit of End Product or Product Mix

The absolute quantity of energy use is related to the production volume of a product or product mix. Energy efficiency measures will result in a lower specific energy use. This indicator is therefore ideal for trending energy efficiency achievements. Sometimes a change in product quality can cause significant changes in energy consumption. If necessary you

have to correct the indicator for these influences.

This performance indicator can be monitored for different time intervals (hour, month or year). The same type of indicator can be applied for main process areas and utilities.

EXAMPLE 1

A chemical plant produces two end products A and B. The production process of each product uses steam and electricity. The table below indicates the hourly energy consumption and production volumes.

The specific energy consumption per tonne of product is the sum of the electricity and steam consumption expressed in primary energy equivalents, i.e. 1MWh electricity = 9 GJprim and 1 GJ steam = 1.1 GJprim.

		Product A	Product B	Product mix (A+B)
(figures per hour)				
Energy input				
Steam	tonnes	5.0	20.0	25.0
	GJ steam	12.5	50	62.5
Electricity	MWh	3.0	1.0	4.0
Production	tonnes	12	15	27
Total input as primary energy	GJ prim	40.9	64.6	105.4
Specific energy consumption	GJ/tonne	3.41	4.30	3.91

BP 2 8.3. Specific Energy Consumption Related to the Reference Value in the Reference Year

This performance indicator is called the Energy Performance Index (EPI). The value for the specific energy consumption in the reference year is set at 100%. For each consecutive year the specific energy is expressed as a percentage of the reference value. The EPI thus provides a trend in specific energy consumption over the years. The same can be done per month, week, day, etc.

EXAMPLE 2

Suppose the specific energy consumption of product B in Example 1 is trended over a number of years. The table below gives the trending in the form of the Energy Performance Index. This is the specific energy consumption compared to a reference year.

Spec en consumption product B		
Year	GJ prim/Tonne	%
2000	5,40	100
2001	5,04	93
2003	4,68	87
2004	4,43	82
2005	4,25	79
2006	4,12	76
2007	4,07	75
2008	4,03	75

Start of energy management in 2000

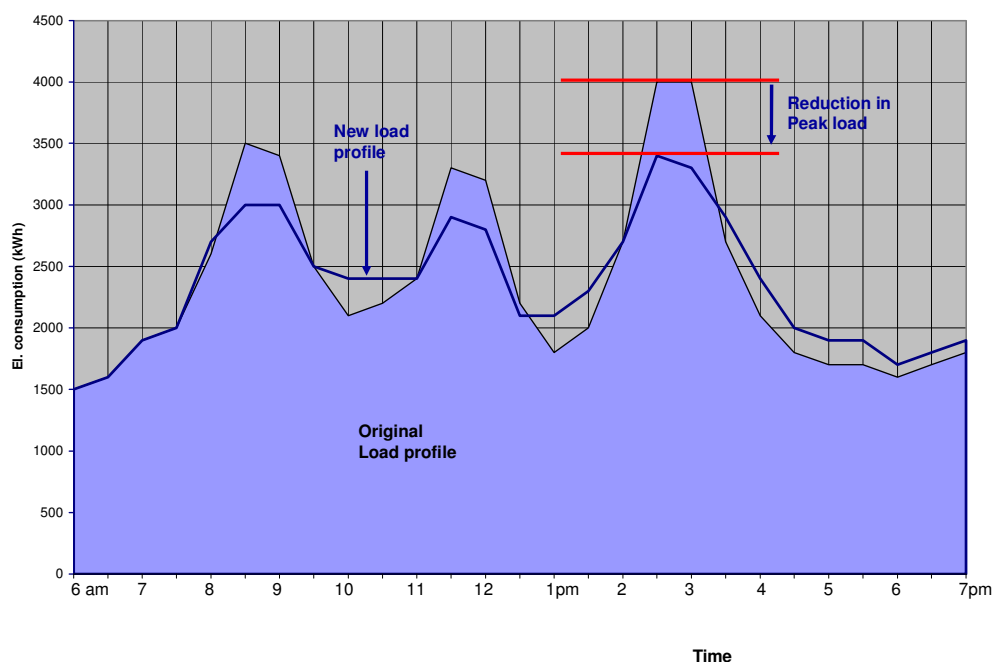
BP 2 8.4. Load Profiles to Identify Peak Loads

In industrial production, peak loads can occur in the electricity and steam consumption, for example with batch processes. Peak loads cause inefficiencies and can substantially increase the purchasing costs of energy. This can be the case for both your electricity and natural gas purchases. Therefore, avoiding peak loads or lowering them can create substantial savings.

To investigate your load profiles you need energy input data over a sufficiently short time interval (for example ½ hours readings). Plot your energy data against time in a graph to visualise the load profile and investigate the relationship between the production process and the energy consumption to see whether a reduction of peak load can be achieved. With these load profiles you will also see (and be able to analyse) other factors that might affect the energy consumption, such as for example a change in product quality.

Figure 6 gives the electricity consumption per ½ hour for a small chemical company over the day time before and after measures have been taken to reduce the peak load.

FIGURE 6. HALF HOUR ELECTRICITY CONSUMPTION



As can be seen in the new situation the base load electricity consumption has increased somewhat, but the peak load is substantially reduced.

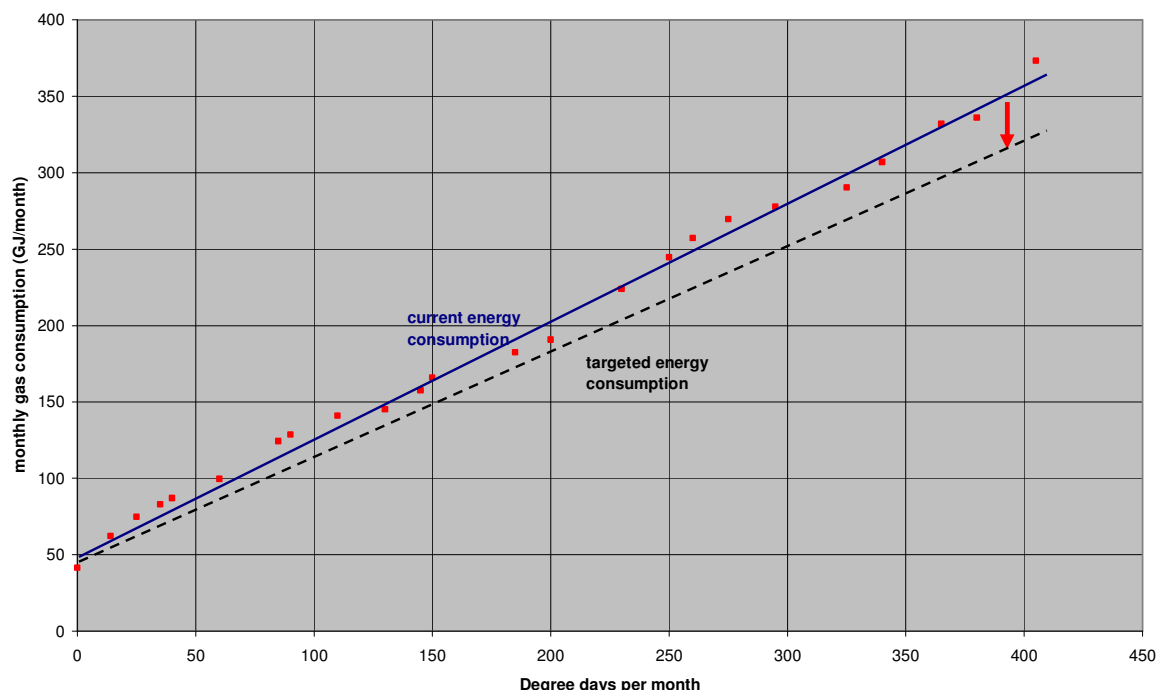
BP 2 8.5. Energy Consumption of Buildings in Relation to Outside Temperature

Energy for heating and air conditioning (cooling) is influenced by the outside temperature but determined by the level of insulation and other energy savings measures in the building. A good performance indicator for the energy consumption of buildings is the energy use in relation to the outside temperature.

A more advanced approach is to make use of the Degree-Days method. Degree days are a measure for the severity and duration of cold weather. In essence, it is a summation over time (normally a month) of the differential between the daily average outside temperature and a reference inside temperature. The colder the weather in a month the higher the degree

days number. So the energy use of buildings can be related to the degree days, as shown in Figure 7. This graph gives for 24 months the energy consumption of a building plotted against the degree days of that month. The blue line is the current relationship; the dotted line can be used for target setting of energy savings measures in the building.

FIGURE 7. USING DEGREE DAYS TO SET TARGETS



To use this method check whether degree days information is available in your country, otherwise you could make a relationship with monthly average ambient temperatures, which will give a slightly less accurate result. More information on degree days can be found in Best Practice 6.

BP 2 9. Further information

Best Practice Example How to Account and Analyse Your Energy Use

Using a meter to help monitor your energy typically identifies energy savings of more than 5%, and this investment is often repaid in less than one year.
(Carbon Trust)

The Audits under CARE+ have shown that without a proper energy accounting it is difficult to monitor the energy use and detect energy saving opportunities. One of the companies doing the CARE+ Audit have an all-inclusive total management system that keeps under control production, technical and maintenance activities, energy consumption-cost, quality, environment, accounting, administration. The coordination of electricity use by different equipments in all departments avoids for example peak penalties, which would not be possible without a well established energy accounting. This has supported the energy efficiency efforts of the company in recent years and helped them to achieve energy savings of around 43%, on base load consumption.

BP 2 9.1. Additional reading

1. CARE+ Energy Efficiency Self Audit Guide Excel sheet templates
www.cefic.org/careplus
2. How to monitor your energy use, Carbon trust publication GIL157
www.carbontrust.co.uk
3. Monitoring and targeting; Techniques to help organisations control and manage their energy use, Carbon Trust publication CTG008;
www.carbontrust.co.uk
4. Système International d'unité – Bureau International des Poids et Mesures
www.bipm.org

Best Practice 3 How to Set Up and Run an Energy Information System

BP 3 1. Introduction

Energy efficiency is strongly dependant on the available data on energy consumption. Best Practices 1 and 2 already referred to data collection. However, this Best Practice goes more into detail and recommends how to ideally collect and manage information relevant for energy efficiency. An energy information system is meant to support the energy management programme in providing accurate and consistent information about the current and historical energy use of your plant. It also will show how the energy efficiency and energy costs are improving. It is, therefore, an indispensable element in an energy management programme.

BP 3 1.1. Find an Appropriate Solution

There are a huge variety of energy information systems, ranging from manually read instrumentation and simple spreadsheet analyses, to sophisticated computerised database systems. The features and elements of the energy information system should be appropriate to the specific needs of your company and your energy management programme. The optimum solution depends on:

- Your need for information as defined in the energy management plan.
- The particular nature of your site, the complexity of the energy situation, and the processes and equipment involved.
- The total energy costs in relation to the total production costs.
- The level of achievable cost savings as estimated in the energy management programme.
- The level of existing data infrastructure that can be integrated into the energy information system.

In many cases, the optimum solution is a compromise between budgetary constraints and fulfilling the total information need. It is important to make sure that the compromise solution will work and that it leaves room for a gradual growth and improvement.

For companies that still have to start with an energy information system it is advisable not to start with too complicated a system and to develop this tool in an organic way together with the extension of the energy management scope, in order to avoid the risk of losing the credibility of the system. This means that setting the priorities and the defining energy performance indicators in the energy management programme that should be in balance with what can be measured.

It can be worthwhile consulting qualified suppliers of energy information systems in order to get the most appropriate solution.

BP 3 2. Deliverables

The energy information system should deliver the following information:

- Actual information about the current energy performance of processes and equipment.
- Early detection of deteriorating performance of equipment.
- Supportive information to improve control settings of processes.
- Insights into where, when, and how energy is being used, i.e. breakdowns of energy use and costs by product or product mix, and process parts.
- Analysis of historical performance and evidence of energy efficiency achievements.
- Supportive information for effective energy purchasing and cost accounting.
- Historical relationships between production and energy use to support forecasting future energy needs.
- Supportive information for the justification of energy projects.
- Historical information for energy surveys and audits.

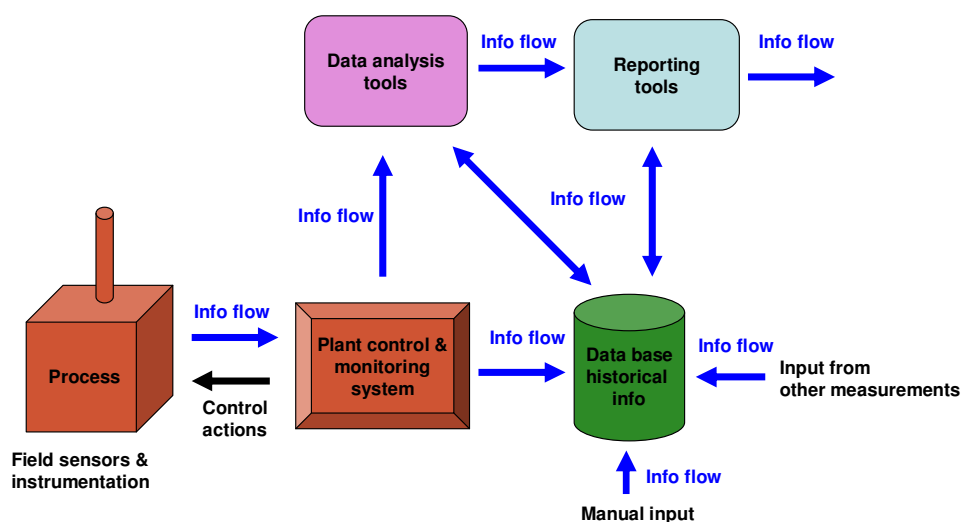
To be able to provide this information the energy information system should be equipped with an adequate database with stored historical energy information and data about influencing factors such production figures, ambient conditions, etc.

BP 3 3. The Elements of an Energy Information System

An energy information system comprises a number of components that are integrated to form a complete data monitoring and reporting system.

The basic elements include field instrumentation that provides the measured values (see Figure 8). They are connected to the monitoring system that gathers all the measured values. These input data are stored in the historical database. The data analysis tools use the information from the database to provide all the analyses of the energy performance indicators. This information is used in the reporting tool to generate the ultimate output for the energy management programme.

FIGURE 8. BASIC SCHEMATIC OF THE ENERGY INFORMATION SYSTEM



It may well be that parts already exist in the present operations and can be integrated into the system. Often the limiting factor is the present level and quality of instrumentation and monitoring.

The following checks and actions should be taken to evaluate this:

- Check whether the present instrumentation and plant monitoring system is suitable to measure, record, and archive the input data that are required for monitoring the defined energy performance indicators and energy savings actions. Quantify what is missing and what improvements are necessary.
- Check whether the present data analysing tools are suitable for making the required analyses and quantify what improvements are necessary.
- Check the key engineering documentation and update to “as built status” if necessary (electrical one line diagrams, process flow schemes, piping and instrument diagrams, etc.).
- Check the calibration and maintenance procedures in order to secure good quality instrumentation.
- Consider the use of temporary and portable meters. This could, for example, be clip-on flow meters to measure natural gas flows and water flows such as boiler feed water, etc. For measuring electricity consumption at certain points, temporary ampere meters could be installed. This is a quick step to generate additional information that can support energy savings actions.

From this check, an energy information plan can be made to step by step improve the system elements where necessary.

BP 3 4. Integral Part of the Plant Control System

As indicated in Figure 8, the energy information system should not be a stand-alone system but, as much as possible, integrated in the process monitoring and control system(s) of the plant. This will ensure that the information is consistent with operational data and makes energy a natural part of the daily operations.

BP 3 5. Quality of Data Gathering

An important aspect regarding the quality of field instrumentation and the monitoring system is the strong preference to work with real-time data in the energy information system. Real-time data are collected automatically at predetermined intervals. To enable this, the instrumentation and the monitoring system must be equipped with the necessary facilities. Real-time data collection in combination with good calibration and maintenance procedures ensure consistent and accurate input data for the various analyses.

BP 3 6. Which Energy Data Should Be Monitored?

Which energy data the energy information system has to provide should be specified in the energy management programme. The frequency of data collection depends upon the specific purpose of the measurement and also should be defined in the energy management programme.

The energy information system must be sufficiently flexible to cope with different interval settings for different readings. For example, for a process installation that uses substantial energy in varying quantities reporting every 15 minutes may be appropriate, while for a base load refrigeration unit reporting once a month may be sufficient. It is important to measure peak load in energy use, so the pertaining time intervals should be short enough to measure these.

BP 3 7. Energy Data Analysis

The energy information system must be suitable to provide the data required for the analyses as specified in the energy management programme.

In addition to analysing actual values, trending of historical data should be possible. The energy management programme should define what information is to be trended, but the energy information system should be set up with sufficient flexibility to make whatever relationship is wanted within the limits of what is being measured.

BP 3 8. Further information

1. Energy Management Information Systems, Office of Energy Efficiency of Natural Resources Canada
<http://www.oeenrcan.gc.ca/publications/industrial/EMIS/index.cfm?attr=24>

Best Practice 4 How to Improve Your Steam Generation Performance

BP 4 1. Introduction

Steam is one of the most commonly used heat carriers in the chemical industry, and is therefore a main target for energy savings.

The total steam system performance comprises:

- the steam generation in the boiler
- the steam distribution
- the use of the steam at the consuming processes (consumers)

This Best Practice provides possible energy efficiency improvements with steam generation, distribution and the collection and re-use of condensate from the process consumers. The options how to save steam in processes is being discussed in a separate Best Practice that deals with heat integration and waste heat recovery.

BP 4 2. Boundary Limits, Measurements and Definitions

To consider your scope for energy savings you should have a clear picture of all major energy flows involved in your steam generation. Furthermore, it is useful to define clear boundary limits for the specific areas in order to measure performance improvements on a consistent basis.

FIGURE 9. ENERGY INPUT AND OUTPUT OF THE BOILER HOUSE

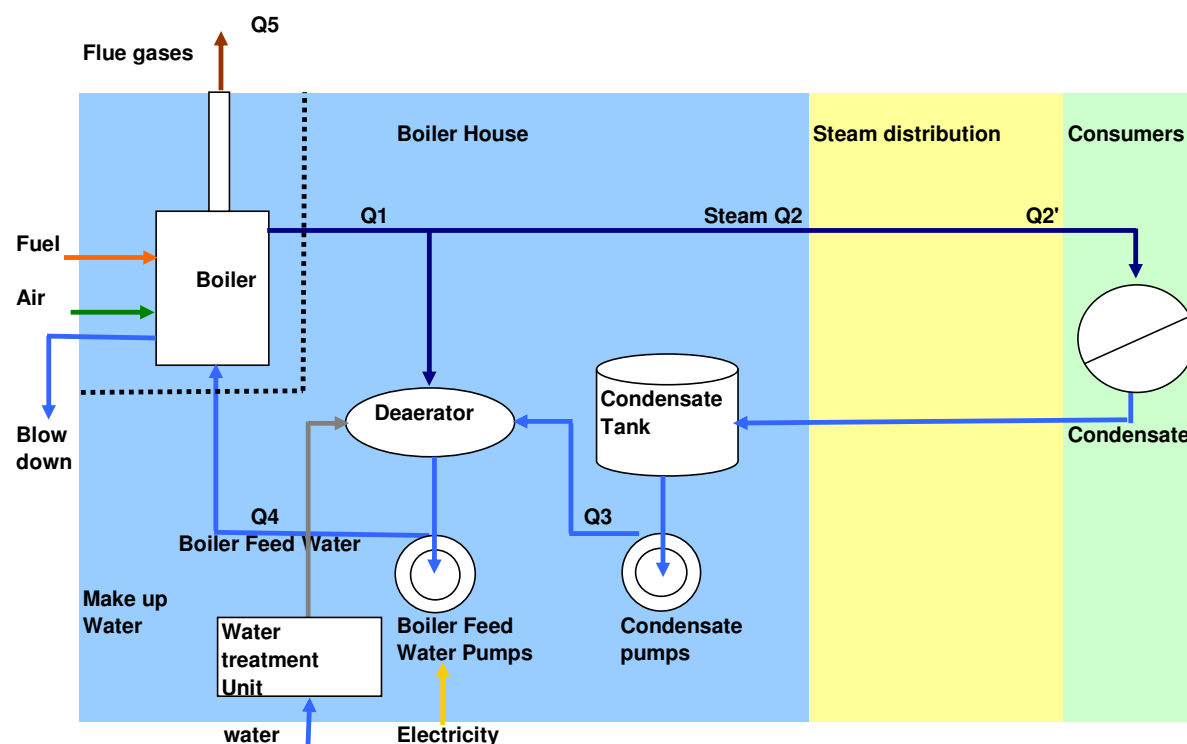


Figure 9 shows a simplified scheme of the main energy flows entering and leaving your boiler house. The boundary limit of the individual boilers is indicated with the dotted line. The boundary limit of the boiler house is indicated by the blue area, and the steam distribution with the yellow area. The consumers are in the green part of the diagram. In practice, you can use your Process Flow Diagram to mark the detailed boundary limits.

To define and measure energy efficiency achievements with your steam generation and distribution you must be able to measure and quantify the main energy flows involved in

steam generation and use. (Please be aware that throughout this section, reference is made to Figure 9).

- To determine the heat content of the steam Q1 (as GJ steam) leaving the boiler you have to measure the volume flow of steam and the pressure and temperature at that point. With these data you can calculate the tonnes of steam and the enthalpy (tonnes x enthalpy = GJ), in order to calculate the energetic content of your steam.
- The heat content of the steam leaving the boiler house Q2 is Q1 minus all internal steam use, such as for the deaerator. As a minimum, it is appropriate to measure flow, pressure and temperature at the Q2 point.
- At the consumers you should at least measure the steam consumption Q2' of the major process areas. Often, steam consumption can also be calculated from process parameters and condensate flow measurements.
- Return condensate heat Q3 (as GJ condensate), entering the boiler house, is calculated from measuring the cubic metres of condensate and the temperature and pressure of condensate.
- The heat content of the boiler feed water entering the boiler can be calculated by measuring water flow, together with the pressure and temperature (these are normally at the deaerator settings).
- With the mass- and energy balance over the deaerator you can calculate the amount of steam that is used in the deaerator.
- The electricity consumption (as kWh) is mainly for boiler feed water pumps, combustion air fans and condensate pumps. The electricity consumption of the boiler house should be measured separately.
- The heat loss in the flue gases Q5 (as GJ) leaving the boiler is calculated from the flue gas flow and the temperature of the flue gases. The enthalpy of the flue gases is proportionate to this temperature. The flue gas flow can be derived from measuring the combustion air flow and fuel flow. If O₂ in the flue gases is being measured and the fuel composition is known, you can also calculate the flue gas quantity using these parameters (also see later with air/fuel ratio control).
- The combustion air is normally measured at the air fan
- The fuel flow, or flows in case of dual fuel firing, should be measured for each individual boiler, and the fuel composition and heating value should be known.
- Other heat losses to take into account are:
 - Radiation losses of boilers, piping, valves and equipment in the boiler house.
 - The boiler blow down system.

These steps are discussed in more detail in the following sections. Please be aware that the analysis can either refer to one boiler or all boilers that you have on your site.

In each of these areas, there are possibilities to improve energy efficiency, resulting in less fuel per tonne of steam needed. As already discussed, this Best Practice does not discuss how much steam is needed in the process at the consumers; this is addressed elsewhere.

To assess your improvement measures it is helpful to use the following efficiency definitions: The overall boiler house efficiency is defined as:

$$\eta_{BH} = (Q2 - Q3) / \text{Fuel}$$

The individual boiler efficiency is defined as:

$$\eta_B = (Q1 - Q4) / \text{Fuel}$$

BP 4 3. Energy Savings in Steam Generation and Distribution

In the following sections, a number of possible fuel savings options are described. Most of them are Good Housekeeping measures, which you can implement directly and at no or very limited costs. Others require an investment, but normally have an attractive pay back period. You will, however, have to make your own business case for these options. Some may only

be feasible if you have to revamp your boiler house, enabling you to make more strategic changes.

As a general remark, your boilers and boiler plant equipment should be inspected and serviced on a regular basis. A well-maintained steam system is a prerequisite for exploring energy efficiency opportunities.

BP 4 3.1. Pressure and Temperature at which Steam is Generated

Check whether the boiler operates at the minimum possible pressure and temperature. The following factors need to be addressed:

- The steam leaving the boiler house should be slightly super heated (20-30°C) to avoid condensation in the steam distribution network and erosion/corrosion problems.
- The steam pressure should be set at the minimum required level for proper distribution to all consumers, taking into account also how the steam supply to the heat exchangers is being controlled.
- If steam is generated for use in steam turbines for power generation or mechanical drives, then the steam must be at the correct pressure and temperature for the optimal functioning of these turbines.

A lower steam pressure will increase the boiler efficiency. In most cases, the condensation heat of the steam is used in heat exchangers to heat up process streams. Check with the consumers what minimum temperature level in the heat exchangers is required and see whether the steam pressure can be lowered.

In cases where you have a fluctuating steam demand, it may be necessary to install pressure regulating valves just downstream the boiler in the steam system and operate the boiler at a slightly higher pressure than needed in the distribution system. This enables the boiler to quickly respond to changes in steam demand and avoid the risk of a boiler trip due to too large steam pressure fluctuations. However if you can avoid peak load demands you can operate the boiler at a lower steam pressure, and save fuel.

BP 4 3.2. Boiler Stack Heat Loss

In the combustion process fuel is burned with the oxygen from the combustion air, which is supplied with the combustion air fans. In the passage through the boiler heat exchanger surfaces the hot combustion gases exchange most of their heat content with the water/steam side. But part of the combustion heat leaves the boiler stack unused with the flue gases. By minimising the stack losses you can save on fuel. This can be achieved by the following two measures (which should be considered also in this sequence):

1. Proper burner tuning and controlling the air/fuel ratio of the combustion system to the minimum amount of air in order to minimise the amount of flue gases.
2. Recovering also low temperature heat from the flue gases.

Burner tuning and the optimal fuel/air ratio control

The flue gas volume flow is determined by the amount of combustion air that is used in the boiler to combust the fuel. In order to achieve a complete combustion an extra amount of air is normally used compared to what theoretically is needed for the chemical reactions (the stoichiometric quantity).

The extra air is expressed with the n-factor: $n = 1.15$ means that 15 % extra air is being used in the combustion compared to the stoichiometric quantity. This extra amount of combustion air is ballast and should be kept to a minimum to realise a complete and safe combustion of the fuel, meaning no forming of unburned hydro carbons and CO in the firebox of the boiler. This can be achieved with a proper air/fuel ratio control over the whole load range of your boiler.

Most boilers operate not at their full load point, it is therefore important to also look at the part load air/fuel ratio setting. Boilers can have different forms of air/fuel ratio control. The

simplest form is where the combustion air control is mechanically linked with the fuel control valve. In that case the air/fuel ratio is preset over the whole operation range of the boiler. You should regularly service this control to make sure that the set ratio is still okay. More sophisticated controls work with separate fuel flow and air flow measurement. These controls enable a trimming of the combustion air volume on basis of the measured O_2 and CO in the flue gases.

So to be able to trim the air/fuel ratio on basis of excess flue gas O_2 you have to have:

- A continuous flue gas oxygen and CO measurement,
- A trimming control of the air flow to the minimum acceptable O_2 in the flue gases.

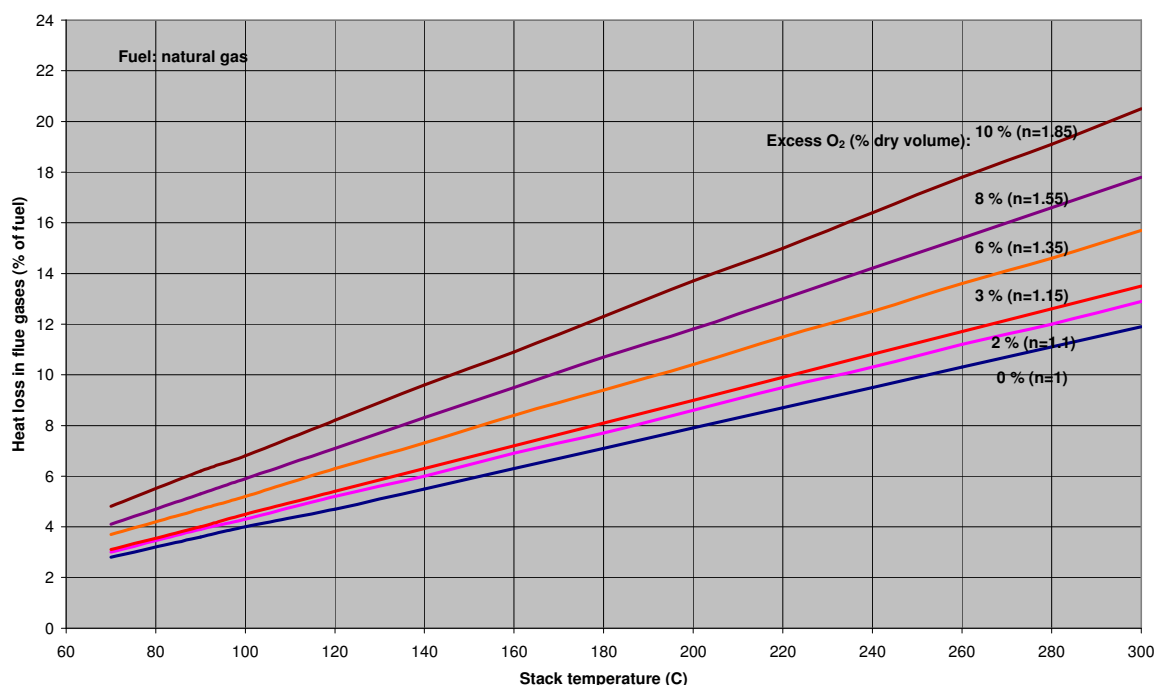
TIP

It is very important that your boiler is equipped with a properly functioning burner management and safeguarding system to continuously supervise the air/fuel ratio control to guarantee a safe combustion process under all circumstances.

The fuel saving that can be achieved with a proper air/fuel ratio control very much depend on the type of fuel and the stack temperature level.

Figure 10 gives a graph where you can estimate the fuel savings by: a) reducing the excess combustion air (lower excess O_2 percentage in the flue gases), and b) further heat recovery (lowering the stack temperature). It gives the stack losses as a percentage of the fuel input as a function of the stack temperature at different excess O_2 percentages (and the related n-factor). The graph is based on natural gas as a fuel.

FIGURE 10. STACK HEAT LOSSES



For example: If your boiler currently operates with 8% excess O_2 and a stack temperature of 240°C and you could reduce these to 3% O_2 and 180°C you would reduce your stack losses from 14.1% to 8%, reducing your fuel input by 6%.

A) Lowering the Boiler Stack Temperature

There are various possibilities to further utilise the heat in the flue gases, depending on your

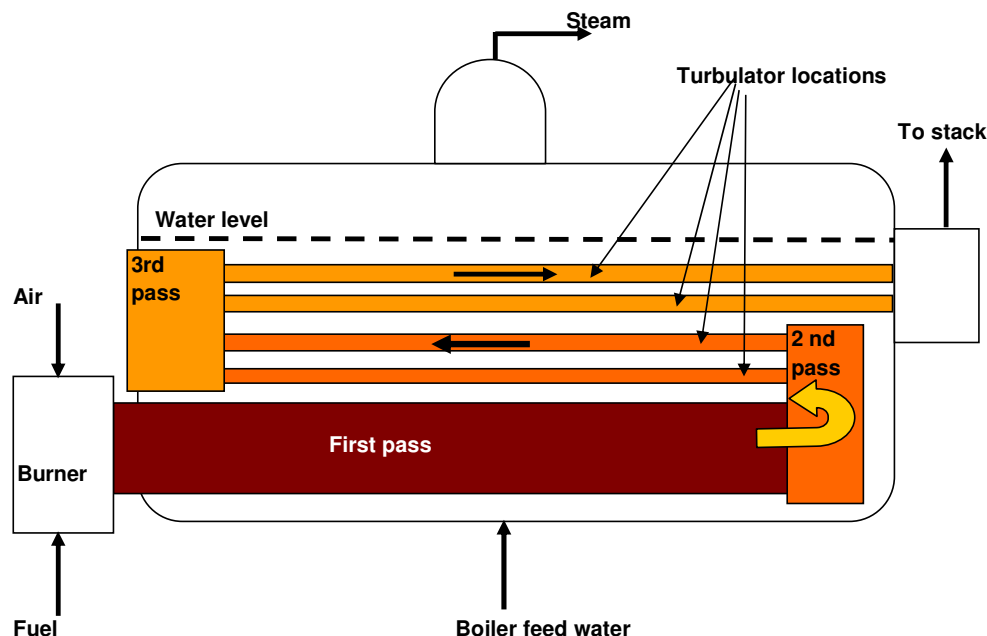
present boiler arrangement and your current stack temperature:

- Using an economiser (if your boiler is not yet provided with one) to heat up the boiler feed water before it enters the boiler.
- The installation of a pre heater to heat up the makeup water before entering the deaerator. The makeup water is normally at ambient temperature, whilst the deaerator operates at 105 to 110°C or higher (depending on the type of fuel).
- The installation of a pre heater to heat up the condensate before entering the deaerator. If the temperature difference between the condensate and the deaerator is more than 30°C there is room for pre heating the condensate without jeopardising the functioning of the deaerator (see under “Deaerator”).
- Using a pre heater to heat up the combustion air (downstream of the air fan). This can be arranged in the form of a twin coil system, consisting of a heat exchanger in the flue gases, a water/glycol circulation system and a heat exchanger in the combustion air. The water/glycol system takes heat from the flue gases and passes it on to the combustion air.

Another interesting option with fire tube boilers is to install turbulators in your boiler.

The packaged fire tube boiler (see Figure 11) is the most commonly used boiler type in small and medium sized chemical plants (maximum capacity approximately 25 tonnes/h and 20 bar steam pressure). In fire tube boilers hot combustion gases pass through long, small-diameter tubes, located in the boiler water area. Heat is transferred through the tube walls into the boiler water to generate steam. These boilers are categorised by the number of passes with which the combustion gases travel across the heat exchanging surface before they leave the boiler. Figure 11 illustrates a three pass boiler.

FIGURE 11. FIRE TUBE BOILER



The hot combustion gases enter the tubes in a turbulent flow, which is transferred into a laminar flow shortly after they entered the 2nd pass and a laminar boundary layer of cooler gas is formed retarding heat transfer into the water. To restore a more turbulent flow so called turbulators can be inserted into the tubes increasing the heat transfer. Turbulators are coiled steel strips that can be inserted into the 3rd and 2nd pass. They can also function to balance the total heat transfer over the tubes. They will increase the boiler efficiency (more steam per fuel, and lower stack temperature).

Note, that if higher pressures or steam volumes are required then water tube boilers will be used. Water-tube boilers differ from fire-tube boilers in that the water is circulated inside the tubes, with the heat source surrounding them.

Below an example is given of what fuel savings can be achieved with an economiser. Figure 12 shows two boiler types that generate 20 tonnes/h of 10 bar 200°C steam. One is without economiser, here the boiler feed water from the deaerator is directly fed into the evaporator. And the other is with an economiser where the boiler feed water is heated up to approximately 145°C. The stack temperature at the boiler without the economiser is 230°C and with the economiser 140°C.

FIGURE 12. FUEL SAVINGS WITH AN ECONOMISER

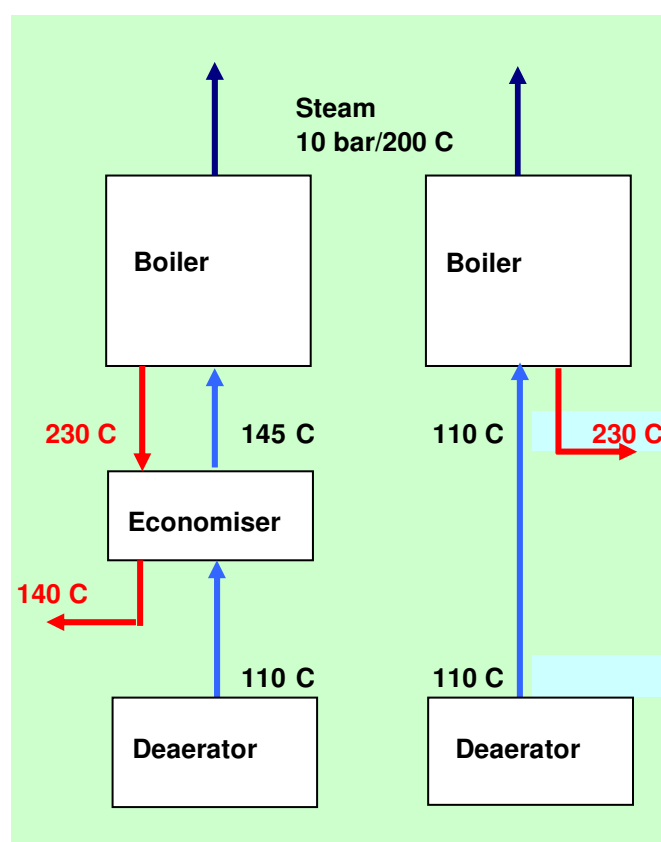


Table 15 below gives the percentage fuel savings with an economiser for a 20 tonnes/h steam boiler.

TABLE 15. SAVINGS FROM THE ECONOMISER

			No Eco	With Eco
Steam	tonnes		20	20
	pressure	bar	10	10
	temperature	C	200	200
Boiler feed water:	tonnes		21	21
	temperature	C	110	110
Eco out temperature		C		145
Stack temperature		C	230	140
Boiler efficiency		%	86	90
Fuel per tonne steam	GJ/tonne		2.750	2.6
Perc fuel saving		%		4%

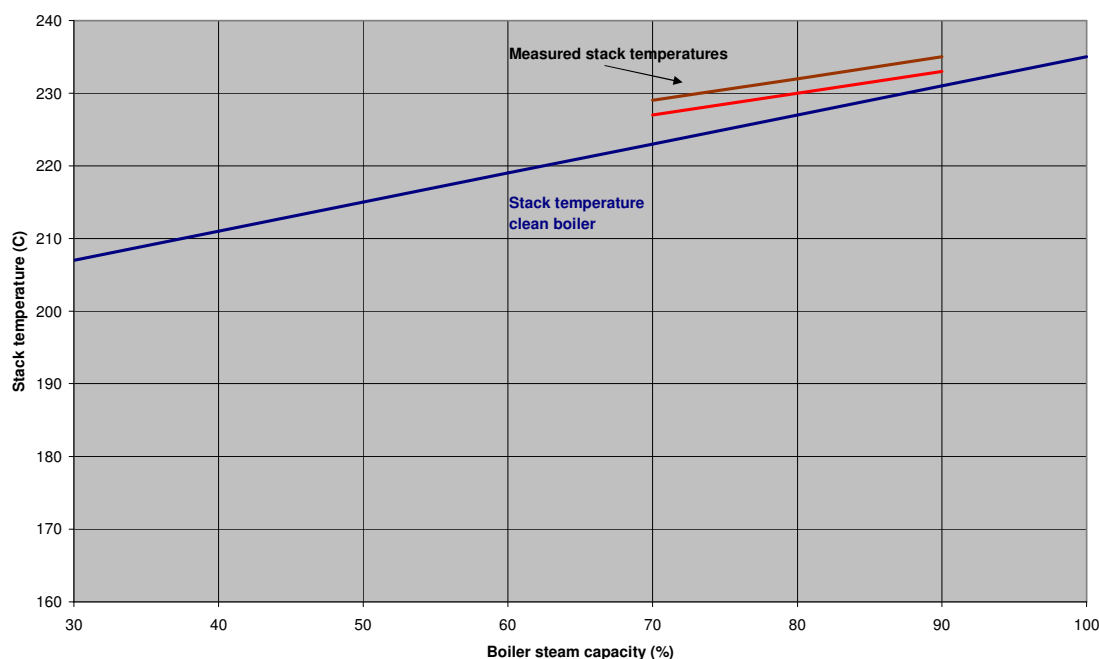
In case you burn sulphur containing fuels the minimum stack temperature should stay above the sulphur dew point (SO_2/SO_3) of the flue gases (boiler feed water above approximately 140°C), and for fuels without sulphur, such as natural gas, above the water dew point of the flue gases (boiler feed water above 70°C) to avoid serious corrosion in the economisers and pre heaters.

With natural gas as a fuel you could even consider to install condensing economisers of stainless steel, which are able to use also part of the condensing heat of the formed water vapour in the flue gases for low temperature useful heat.

B) Boiler Fouling and Stack Temperature

It is important to know the relationship between flue gas temperature and the steam production of your boilers. If there is scaling or fouling in your boiler this temperature will rise, giving you a clear signal to clean your boiler. This is illustrated in Figure 13. It gives the flue gas temperature of a boiler after the evaporator (before entering the economiser).

FIGURE 13. FLUE GAS TEMPERATURE IN RELATION TO BOILER CAPACITY



BP 4 3.3. Power Consumption in the Boiler House

The main power consumers are the boiler feed water pumps and the combustion air fans. Because of the crucial stand-by function, normally 2 x 100% or 3 x 50% of the required pump capacity is running, each with high throttling losses. To save energy with your boiler feed water pumps you can consider to install variable speed drive. See for more information the Best Practice 7 on Variable Speed Drives and Motors.

Check the efficiencies of the various pumps in the boiler house. If they operate with a poor efficiency (below 50%), consider what you can save with a revamp to a more efficient pump unit including an efficient motor.

BP 4 3.4. Radiation Losses

Radiation losses take place from hot boiler surfaces and piping, valves and other equipment such as vessels and pump. For a well maintained boiler radiation losses are approximately 1% of the boiler thermal capacity. These losses are a fixed amount independent of the boiler load. As most boilers operate at part load radiation losses should not be ignored. You should regularly inspect insulation and repair where necessary. Use removable insulation on

valves that are regularly used.

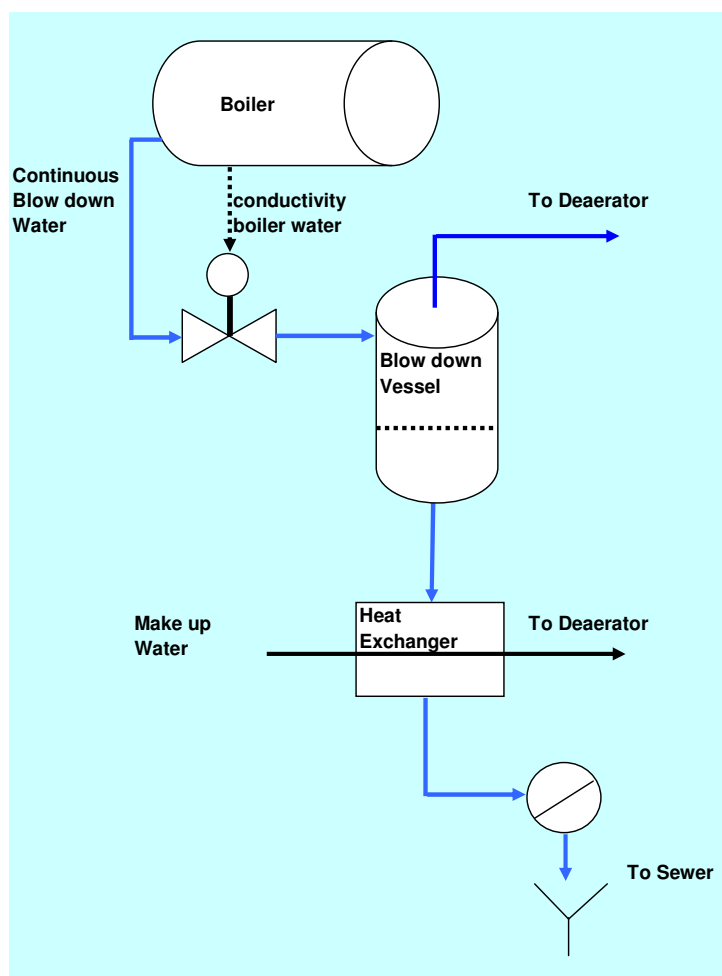
BP 4 3.5. Deaerator Operation

The return condensate and make up water are fed into the deaerator, to remove oxygen and free CO₂ from the boiler feed water to avoid corrosion in the boiler. This is achieved by spraying the condensate and make up water in the upper steam part of the deaerator. There, by heating up the water, these gases with part of the steam are evacuated from the deaerator. Normally a temperature rise of the incoming water of 10 to 15°C is sufficient to achieve acceptable rest oxygen content in the boiler feed water of less than 10 ppb (parts per billion). The deaerator operates at a fixed pressure (and saturation temperature) by supplying a controlled quantity of steam into the deaerator. The pressure set point should not be set too high because this would require too much steam to heat up the incoming water (which is a rather inefficient way of heating up the boiler feed water). A normal pressure set point ranges from 1.2 to 1.5 bar (temperature 105 to 110°C).

BP 4 3.6. Boiler Blow Down

In order to avoid accumulation of contaminants, such as chlorides, sulphates, etc. in the boiler water a continuous and regular discontinuous blow down of a certain percentage of boiler water needs to take place to control the boiler water quality. The required blow down rate can be minimised by good boiler feed water treatment (for more details see Section 3.12). The heat in the blow down water should not be wasted. You can recover this heat in a blow down flash tank. The flash steam can be used in the deaerator. The heat in the remaining blow down water can be further utilised to heat up the makeup water. A schematic of an energy efficient blow down system is given in Figure 14.

FIGURE 14. CONTINUOUS BLOW DOWN



BP 4 3.7. Combustion Air Intake

With indoors boilers the intake point for combustion air should preferably be in the top of the boiler house, to take in warm air. If there is still room for further reduction of the temperature of the flue gases you can consider installing an air pre heater to pre heat the combustion air. This will increase the boiler efficiency.

TIP

As a rule of thumb: each 20 °C temperature increase of the combustion air will reduce the fuel consumption in the boiler by 1%.

BP 4 3.8. Steam Distribution

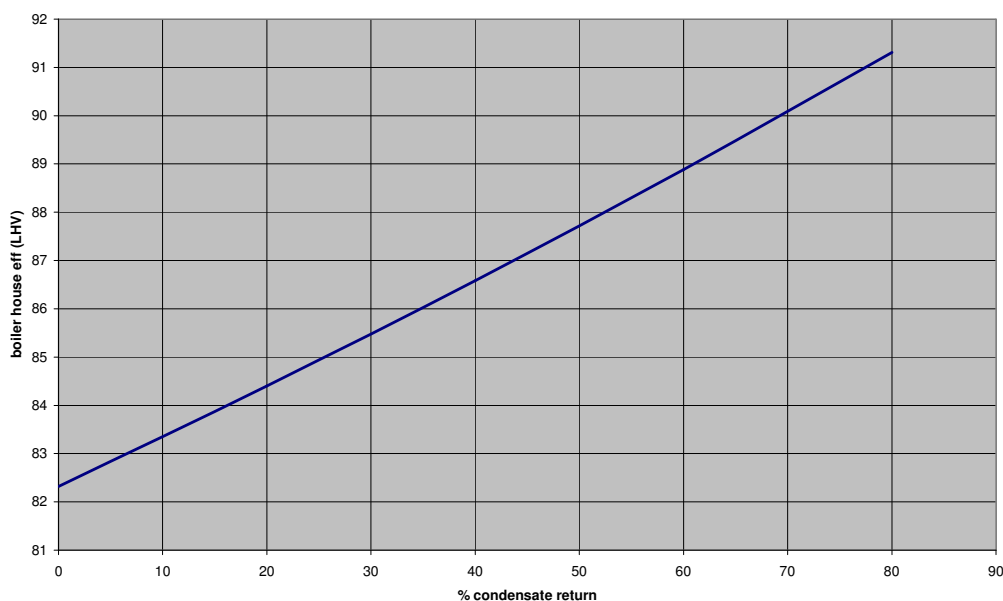
Supply dry clean steam to the consumers. Supply lines should be correctly sized to avoid too high pressure drop over the system and the risk of erosion/corrosion due to too high velocities. The piping support must be properly designed to cope with expansion due to temperature changes. Supply lines should have proper insulation and be equipped with sufficient number of steam traps to quickly remove any formed condensate in the lines. Isolate unused parts of the steam distribution from the system with properly located isolation valves.

BP 4 3.9. Return Condensate

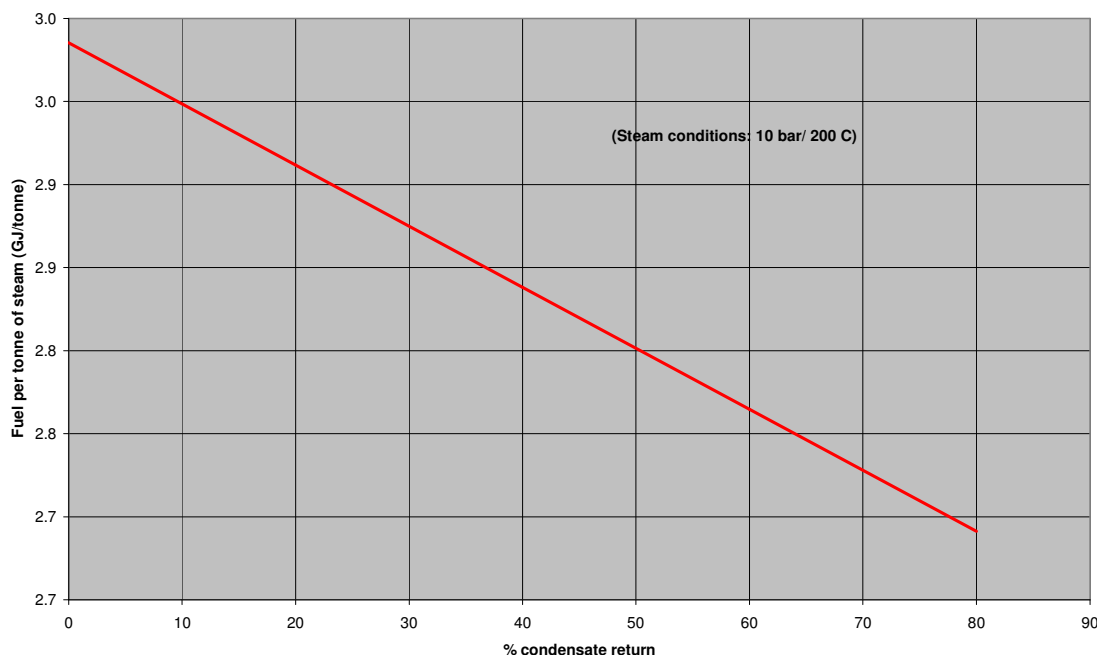
Collecting and returning the condensate back to the boiler house often creates a substantial energy saving. You should however know where the returned condensate comes from and whether it is free from contaminants, such as organic components, chlorides, etc, to re-use it without the risk of serious corrosion problems in your boiler. Monitoring the quality of the condensate, especially for organic components, is an important precaution.

Figure 15 illustrate the positive effect of condensate return on boiler house efficiency.

FIGURE 15. IMPROVEMENT OF BOILER HOUSE EFFICIENCY WITH RETURN CONDENSATE



As can be seen the overall efficiency of the boiler house can improve 10 percentage points when up to 80% of the condensate is recovered. This can create substantial fuel savings as illustrated in Figure 16.

FIGURE 16. REDUCTION OF FUEL NEED PER TONNE OF STEAM BY RETURN CONDENSATE


To enable collecting and re-use of condensate proper design of the condensate draining and return system is of utmost importance. Poor drainage of condensate can result in poor performance of heat exchangers, in erosion/corrosion and water hammering in the condensate system.

It is beyond the scope of this best practice to provide a full detailed design and engineering guide for condensate systems. However, a number of common good design practices are summarised below:

- Make sure steam traps and condensate lines are properly sized. Condensate return lines must be designed on the basis of two-phased flow (water + the flash steam).
- Use the correct steam trap for the application. Consult qualified suppliers to make the right choice.
- Never group individually controlled heat exchangers on the same steam trap, because this can easily lead to clogging of condensate and malfunctioning of heat exchangers.
- Ensure that condensate can easily drain from the heat exchanger and no clogging of condensate is taking place: steam trap should have the right size, there should be sufficient pressure differential over the steam traps to push the condensate out.
- Ensure that piping arrangement around heat exchangers (installation of vacuum breakers, and pressure equilibrium lines, etc.) allows the condensate to drain freely.
- Ensure that steam system pressure, heat exchanger duty control, and pressure in the condensate system are matching to enable proper draining and returning of condensate.
- Tie in of condensate drain lines should always be on top of the condensate return line.

BP 4 3.10. Inspect and Repair Steam Traps

When steam is being used in heat exchangers it is condensed to the water phase. Steam traps are being used in steam systems and at the heat exchangers to remove the condensate. Steam traps are available in quite a variety of forms. It is important to use the right type in the right application. You can consult your steam trap supplier to make sure your steam traps are the correct type and are installed correctly. There is enough useful literature on this subject that you can use. You should inspect the functioning of the steam traps regularly, because if they fail live steam is escaping into the condensate system or to the atmosphere, or, if they plug, water-hammering problems can occur in your condensate system.

Plugging can be detected by using infra red temperature measurement of the surface temperature just downstream the steam control valve and just before the steam trap. If you notice a serious sub-cooling (more than 20°C) this may be a signal for malfunctioning. Steam leakage can often be detected with a visual inspection of the steam trap. Another possibility is to use ultra sonic detection equipment. Most steam traps operate cyclic, so with ultra sonic inspection you can hear whether they function properly.

BP 4 3.11. Use Your Base Load Steam Demand to Generate (Part of) Your Own Electricity Consumption.

Normally in chemical plants most of the steam is used as Low Pressure (LP) steam, i.e. at steam pressures of 10 bar or lower. In cases where there is a base load LP steam demand of approximately 15 tonnes/h or higher over say 6,000 operating hours or more, you can consider using your base load steam demand to generate electricity. This can be realised by installing a High Pressure (HP) steam boiler and a back-pressure steam turbine generator unit. The HP boiler produces steam that is fed to the turbine. There it expands to LP steam, which is then fed into the steam distribution system (see Figure 17 for an illustration). The energy in the HP steam is used in the turbine generator unit to generate electricity. HP instead of LP steam generation requires only marginal extra fuel, so the electricity is generated with a very high efficiency and consequently low variable costs. In your business case, you have to assess this option against the required investment for the HP boiler and turbine unit. In new to build situations this can certainly be an interesting option for energy efficiency.

Figure 17 illustrates this option. It shows a situation where 20 tonnes/h of 5 bar steam is used. The steam is generated in the boiler house at 60 bar, 400°C. This HP steam expands in the back-pressure steam turbine to 5 bar steam. The steam turbine generator unit can generate 2 MWe.

FIGURE 17. BACK-PRESSURE STEAM TURBINE

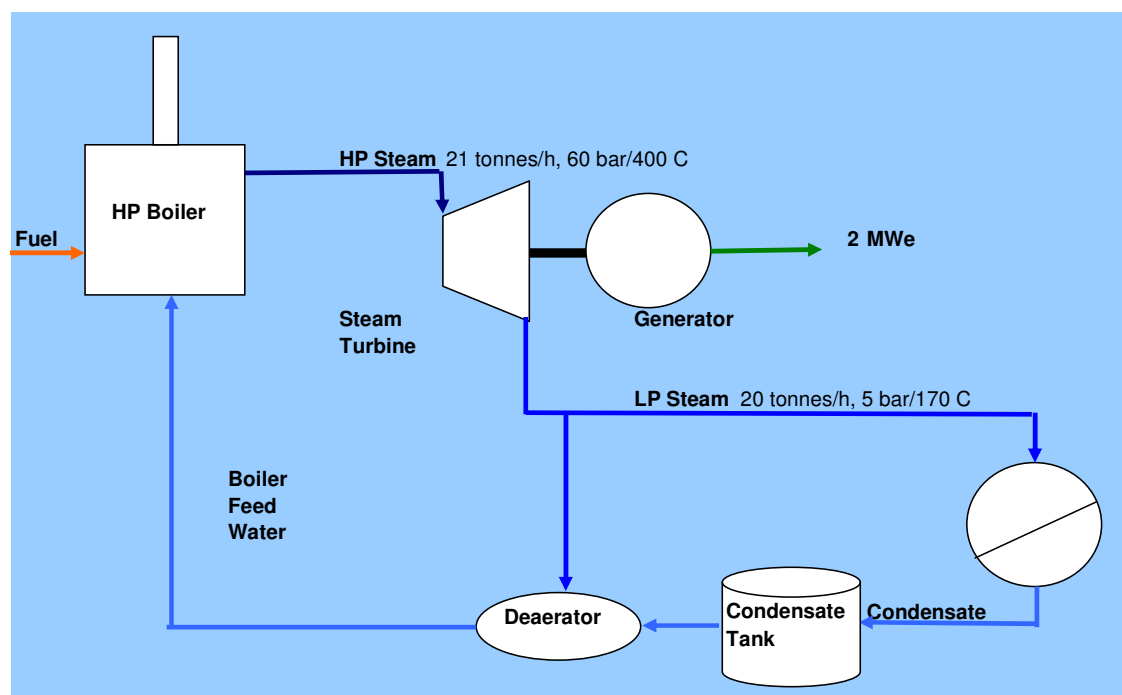


Table 16 gives the comparison with the situation if no steam turbine was installed.

TABLE 16. BENEFITS OF A STEAM TURBINE

		No Turbine	Turbine
Steam conditions consumers:			
Steam	tonnes/h	20	20
pressure	bar	5	5
temperature	C	170	170
enthalpy	MJ/tonne	2789	2789
Steam conditions boiler house:			
Steam	tonnes	20.5	20.5
pressure	bar	7	60
temperature	C	190	400
enthalpy	MJ/tonne	2821	3180
Electricity production:			
Capacity	kW		2000
Output per hour	kWh		2000
per tonne of steam	kWh/tonne		100
Fuel consumption:			
Fuel	GJ/h	56.4	64.6
Extra fuel for electricity:			
Fuel electricity	GJ/h		8.2
El. efficiency	%		88

In the “Turbine” situation more fuel is used, because steam with a higher enthalpy is being generated. Compared to the “No Turbine” situation the extra fuel is 8.2 GJ per hour. With this extra fuel 2 MWh of electricity can be generated, so the electrical efficiency is $(2 \text{ MWh} = 2 \times 3.6 \text{ GJ el})/8.2 \text{ GJ fuel}$ is 88%. Suppose your fuel is natural gas with a price of €6/GJ, then the variable costs of this electricity is €25/MWh. If your avoided electricity purchase costs are €80/MWh your annual savings over 7,000 operating hours per year could be $(80 - 25) \times 2 \times 7,000 = €770,000/\text{y}$.

Note that the installation of power generation equipment on your site will require a thorough technical and financial analysis and probably the use of specialist advice. It will require substantial investment, but can yield very good returns

BP 4 3.12. Optimise Your Water Treatment

In the water/steam cycle a continuous supply of water (“make up water”) is required to compensate for steam and condensate losses, for example if condensate is too contaminated to be re-used, or when steam is being used in the process, etc. Untreated raw water contains contaminants, such as calcium, magnesium, chlorides, and dissolved gases such as O₂ and CO₂, that would cause severe corrosion and scaling problems in the boiler and condensate system. Boiler feed water treatment and boiler water treatment are therefore of utmost importance for a reliable and efficient steam generation.

The following parameters of the water/steam cycle should be checked regularly in order to exclude corrosion phenomena in the water/steam cycle and secure a trouble free steam generation:

- Adequate removal of the water hardness from the make-up water: Ca- and Mg- bicarbonate salts are the main causes of scaling in the boiler. They can be removed from the make up water in a water softening plant, here the water passes a cation filter that exchange the Ca and Mg for Na, thus removing the hardness. For steam boilers up to 20 bar this is often sufficient. For boilers operating at higher pressure a further de-mineralisation of the make up water is often required.

- Keep the conductivity of the boiler water below the applicable standard for your boiler: In the evaporator of the boiler clean steam is formed leaving the contaminants behind in the boiler water. To avoid too high concentrations of these constituents, in particularly chlorides and Na, a certain amount of boiler water is continuously drained via the blow down system. The controlling parameter for that is the boiler water conductivity, which is a good measure for the level of contamination. Check with the available water standards whether your blow down rate operates with the correct setting.
- Keep the pH of the boiler water within the required range of alkalinity: The boiler water must be sufficiently alkaline to form a protective magnetite layer on the steel tubes to prevent acid corrosion in the boiler. This can be realised by dosing a small amount of NaOH.
- Check the removal of CO₂ and O₂ in the deaerator: O₂ and free CO₂ in the condensate and make-up water are removed in the deaerator. The rest O₂ in the boiler feed water should be below the applicable standard for your boiler.
- Check the protective measure to prevent acid corrosion of the condensate return system: The bi carbonates (-HCO₃) in the boiler feed water pass the deaerator and split in the evaporator in CO₂ and water. The CO₂ leaves the boiler with the steam and would cause acid corrosion in the condensate system if no measures are taken. For that reason volatile alkalising, such as ammonia, are added to the water to prevent this.
- Check condensate return for contaminations in particular for the presence of organic components, which would cause corrosion and fouling in the boiler. The check on organic substances in the condensate is a watchdog function. If the condensate is contaminated it must be dumped.

If your organisation lacks the knowledge and experience in the field of water treatment you can consider outsourcing your water treatment to qualified companies.

BP 4 4. List of recommended measures

Below you can find a summary of the Good Housekeeping Measures that have been addressed in this Best Practice:

- Inspect and service your boilers and boiler house equipment regularly, at least once per year.
- Trend the efficiency of each of your boilers at least on a monthly basis in relation to the produced steam.
- If you operate multiple boilers in parallel, apply load management to optimise the overall efficiency.
- Ensure a safe and reliable combustion in your boilers with a burner safeguarding system in place that complies with the safety standards.
- Measure the excess O₂ in the boiler flue gases and trim the air/fuel ratio to the minimum acceptable excess combustion air amount in order to minimise the stack losses.
- Check and repair where necessary the insulation of boilers and piping and valves.
- Ensure that water treatment of boiler feed water, boiler water and condensate return is up to standard and is functioning properly. Make sure that regular analysing of water samples is being done.
- Check the blow down ratio setting with the boiler water quality.
- Check whether the deaerator works at the required minimum pressure.
- Check the functioning of steam traps.

- Check for steam leakages in the system.
- Regularly check for scaling and fouling in the boilers.
- Regularly check heat exchanger surfaces for scaling and fouling.

An additional list of recommended measures, which also might go beyond “good housekeeping” can be found below.

Heat Generation

Low-cost / short term opportunities	
Energy Saving Opportunity	Action to Check
1. Reduce excess combustion air to minimum	1. CO ₂ /O ₂ measurement
2. Maximise completeness of combustion	2. Soot/CO measurement
3. Maintain boiler cleanliness (soot/scale)	3. Monitor for rise in flue gas temperature
4. Repair (replace) boiler insulation	4. Periodic inspection of boiler insulation condition.
5. Insulate feedwater tank and cover tank	5. Check possible feedwater temperature losses
6. Insulate condensate return lines	6. Check possible heat loss from condensate return lines.
7. Optimise quality of make-up water and feedwater	7. Monitor quality of make-up water and feedwater: hardness, acidity, O ₂ .
8. Minimise blowdown	8a. Monitor concentration of dissolved solids in boiler water. 8b. Improve blowdown controls
9. Maintain nozzles, grates, fuel supply pressure/temperature at manufacturers' specifications	9a. Ensure specifications are available and in use. 9b. Regular check and resetting/maintenance.
10. Maximise combustion air temperature	10. Draw air from highest point in boilerhouse.
11. Reduce steam pressure where it exceed system/process requirements.	11. Check system/process needs; adjust controls.
12. Use duct for intake of warmer combustion air	12. Install duct from combustion air intake to higher parts of room.
13. Install an automated gas leakage detector.	-
14. Repair leaks in steam pipework.	-
Higher cost / longer term opportunities	
Energy Saving Opportunity	Action to Check
1. For rapidly varying demand, convert one or more boilers to live accumulator (buffer tank).	1. Monitor/evaluate demand change patterns.
2. Alter controls to “High-Low-Off” or “Modulating-Low-Off”	2. Monitor/evaluate demand change patterns.
3. Install flash steam heat recovery	3. Consider in large capacity situations with high (continuous/frequent) blowdown.
4. Improve combustion controls.	4a. Provide adequate heat input to meet demand. 4b. Minimise fuel/pollution. 4c. Protect personnel/equipment.
5. Waste heat recovery	5a. Economizer 5b. Air heater (recuperator)?
6. Install boiler blowdown heat recovery.	6. Consider in large capacity situations with high (continuous/frequent) blowdown.
7. Use process integration	7. Couple process units that have significantly different heat requirements (i.e. low-pressure steam leaving a high-pressure steam consuming production process can be used for a process requiring low-pressure steam).

Source: www.bess-project.info

BP 4 5. Further information

Best Practice Example How to Improve Your Steam Generation Performance

One of the CARE+ Audit participants has installed a new steam boiler with heat recovery devices (economizer), gaining an annual 12% energy saving on natural gas bill (about 120.000 euro/year). This implies a pay back period of 2.05 years.

BP 4 5.1. Additional reading

1. Steam and high temperature hot water, introducing energy savings opportunities for business, Carbon Trust publication CTV018 Technology overview; www.carbontrust.co.uk
2. Improving Steam System Performance, A Sourcebook for Industry, US DOE, Office of Energy Efficiency and Renewable Energy, www.eere.energy.gov
3. Steam System Opportunity Assessment for the Pulp and Paper, Chemical Manufacturing, and Petroleum Refining Industries, US DOE, Office of EERE, www.eere.energy.gov

Best Practice 5 How to Reduce Energy Use in Your Compressed Air System

BP 5 1. Introduction

Compressed air belongs to the most energy intensive utilities that are used in the chemical industry. Therefore, it is worthwhile to consider energy efficiency opportunities in the production and usage of compressed air. Because compressed air is so convenient and easy to use, it is frequently overused and chosen for applications for which alternatives are more energy efficient and economic. Often people perceive compressed air as a free commodity and are not aware of the relatively high energy costs involved. So, energy savings measures not only focus on efficient production of compressed air but also on how to minimise the use of compressed air and change people's behaviour how to use it.

In this Best Practice the following issues are addressed:

- The assessment of your present use of compressed air, with the aim to find opportunities to reduce the use of it.
- Determining the energy use and energy costs of your compressed air system.
- Opportunities to reduce the compressed air consumption.
- Opportunities to optimise your compressed air supply.
- Other energy savings options in compressed air systems.

BP 5 2. Where is Compressed Air Used in the Process Industry?

In general, compressed air is used in various applications in the process industry:

- As active air for example in transporting goods, for air bearings in precision machinery, etc.
- In certain processes compressed air is being used directly in the process, for example for drying.
- A very widespread application is in industrial vacuum technology to do a variety of handling activities, such as lifting components to an other location, packaging products, etc. Ejectors using compressed air create the necessary vacuum for all sorts of activities.
- As instrument air in various process control activities.
- As plant air, for example for tools, etc.
- There can also be special applications such as breathing air in contained areas

BP 5 3. Assessing Your Current Production and Use of Compressed Air

Investigate where in your plant compressed air is being used, and what the supply conditions are in terms of pressure and dew point. Dew point is the temperature at a certain pressure at which the water vapour in the air will condense. The dew point is normally specified as Pressure Dew Point (PDP) at the supply pressure. Dew point control of compressed air is important in order to avoid condensation in the system, which can cause serious problems in the distribution system and with the users of compressed air.

Air quality classes are given in the ISO standard 8573-1. Compressed air should preferably be produced in oil free compressors to avoid contaminations of lubricant oil traces in the air, which can cause reliability problems in instruments and other end users. Oil separation from lubricant-injected screw compressors and reciprocating compressors is never 100% safe and needs rather intensive supervision and servicing.

BP 5 3.1. Develop a Block Diagram with the Main Components of Your System

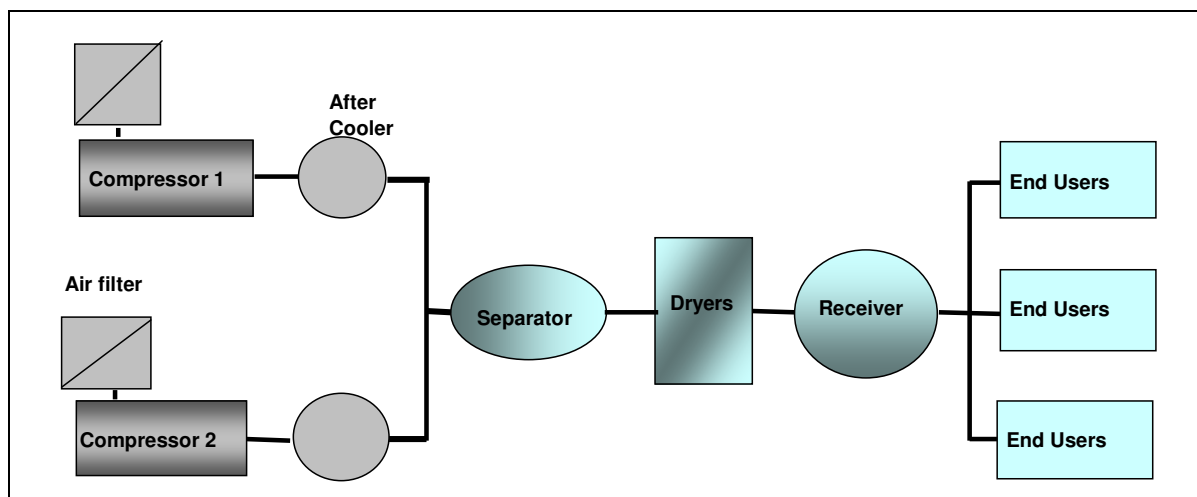
To analyse your present compressed air system it is helpful to develop a block diagram,

indicating the main components of your system with their capacities. Furthermore, the block diagram should contain information on:

- the capacities of the main components (compressors, dryers, receiver);
- the air supply conditions (pressure and dew point);
- where measurements of flow and pressure are located;
- the maximum, average and minimum use of the end users in Nm³/h.

Figure 18 gives a simplified example of the main components in a compressed air system.

FIGURE 18. BLOCK DIAGRAM OF THE COMPRESSED AIR SYSTEM



Air compressors are available in a number of different types. The most commonly used are: reciprocating compressors; screw compressors; and centrifugal compressors. Reciprocating and screw compressors are available in lubricant injected and lubricant-free (or dry) types. With lubricant injected types a lubricant/air separator is required to remove as much as possible lubricant from the compressed air. For a reliable compressed air system it is preferred to use lubricant-free compressor, because traces of lubricant can build up in the compressed air system and can cause serious trouble with end use (for example in instrumentation). Compressed air leaving the compressor is still hot and needs to be cooled in the after cooler. As the air temperature is reduced, water vapour in the air is condensed. This condensate is separated and drained from the system. Air leaving the filter/separator is still saturated. To avoid further condensation downstream in the system the air is dried in the dryers. Their function is to control the water dew point of the compressed air by removing water vapour from the compressed air. The required pressure dew point determines what type of dryer you should apply.

The most common types are:

- Refrigerant dryers, because of their limited dew point range (not below 2 °C) cannot be applied in plants that operate in freezing ambient conditions.
- Regenerative desiccant adsorption dryers use a porous desiccant that adsorbs the moisture in the air. They normally contain two separate units. The compressed air to be dried flows through one unit, while the desiccant in the other is being regenerated. Also deliquescent dryers are used. They use a drying medium that absorbs, meaning that the desiccant medium is used up as it changes from solid to liquid and cannot be regenerated. This type of dryers can achieve pressure dew points to – 40 °C.
- Membrane technology dryers use membranes that allow air molecules to pass through a semi permeable membrane (pressure dew point up to – 20 °C).

BP 5 3.2. Quantify Your Compressed Air Consumption and Electricity Use

How accurate the quantity of air and the related electricity consumption can be investigated depends upon what measurements are taken in your system.

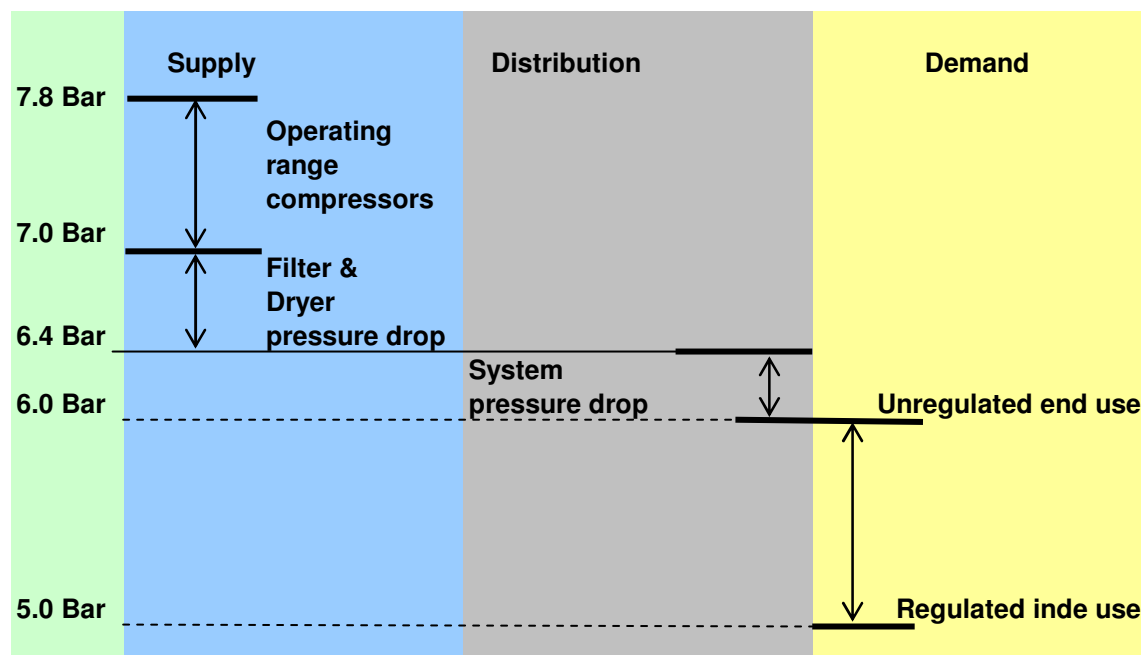
- If you have flow meters installed in the air supply lines and you also measure the electricity consumption of the compressors these measurements will provide the required information on the supplied air quantity and the related electricity consumption.
- If you have no flow meters yet and no electricity measurement, you can get indicative values for the supplied air quantities and related electricity consumption on basis of the recorded full load hours of the compressors and the (known) Vendor specifications of compressor capacity (Nm^3/h , or Nm^3/min) and electricity consumption of the compressors. If the zero load hours of the compressors are also being recorded, you can include this information in your calculation of the electricity consumption.

As a check, you can use temporary Ampère meters to get an indicative measurement of the electricity consumption.

BP 5 3.3. Develop a Pressure Profile of Your System

Another helpful tool in analysing your system is to draw a baseline pressure profile of the system. This shows the pressure drops through your system at a given flow. This information will provide input for control adjustments and monitoring pressure drops over filters, coolers and dryers. An example is given in Figure 19.

FIGURE 19. PRESSURE PROFILE COMPRESSED AIR SYSTEM



This requires a number of calibrated pressure and differential pressure measurements:

- Pressure of inlet air to compressors.
- Pressure at compressors outlet (preferably also at inter stages of multi stage compressors).
- Differential pressure over after cooler, filters, and dryers.
- Pressures at appropriate points in the distribution and at the end users.

You should take pressure measurements at various points in time in order to understand how your system is functioning. Preferably, data loggers should be used to trend airflows and

system pressures accurately. This information will help you to optimise your compressor load profile and consequently the electricity consumption.

BP 5 3.4. Make an Air Balance

As a third step in assessing your compressed air use you can make a compressed air balance, which will provide valuable information for your investigations where there is scope for improvements. An example of an air balance is given in the Table 17.

TABLE 17. COMPRESSED BALANCE

1) Compressed air production					
		Capacity	Running hours	Production per	
		Nm ³ /h	per month	month	
Compressor 1					
Compressor 2					
Total production				X	
2) (Estimated) compressed air consumption					
Site area	User Type	Quantity	Specific use	Hours per	Consumption
			per type	week	n per week
			Nm ³ /h		Nm ³
Process A	Spray nozzle	10	12	30	3600
	Vacuum system	1	20	40	800
Process B					
					
.....					
Total consumption					Y
3) Balance					X - Y

Include in your balance also the minimum required air pressure and dew point at the consumers.

BP 5 3.5. How to Quantify Leakages

The Balance in the Table 17 also includes leakage losses. Leakages can be detected by, for example, checking the system with ultra sonic measurement. To quantify leakages is more complicated. One possibility is to do a leak test run with one of the air compressors, whilst all legal consumers are shut down (at least the once for which the air consumption cannot directly be quantified). During this test the time is recorded the air compressor is running to restore the air pressure. If for example the compressor runs 10 minutes over an hour at full capacity to restore the air pressure the leakage is 1/6 of the compressor capacity. A more accurate measurement can be taken during this leak test operation if the airflow of the compressor is measured. Another possibility is to measure the time it takes and for the pressure in the air storage vessel in the system to drop 1 or 2 bars in pressure, with the compressors shut down, and with all legal air users disconnected from the system. The leakage volume is then:

$$VL = VS \times (p1 - p2)/t$$

Where: VL = Leakage volume (m³/min)
VS = Volume storage vessel (m³)
p1 = begin pressure in storage vessel (bar)
p2 = end pressure in storage vessel (bar)
t = time (minutes)

BP 5 3.6. Improving Your Measurement and Data Logging

Consider the benefits of improving your metering. Alternatively, you could consider using temporary flow measurements and ampere meters to monitor your compressed air production and usage during certain periods.

BP 5 4. Determine the Energy Use and the Costs of Your Compressed Air System

Energy costs form the major part of the total compressed air costs. Typically, the following split can be made:

- Energy costs: 75% of the total air costs
- Capital costs: 13%
- Maintenance and other costs: 12%

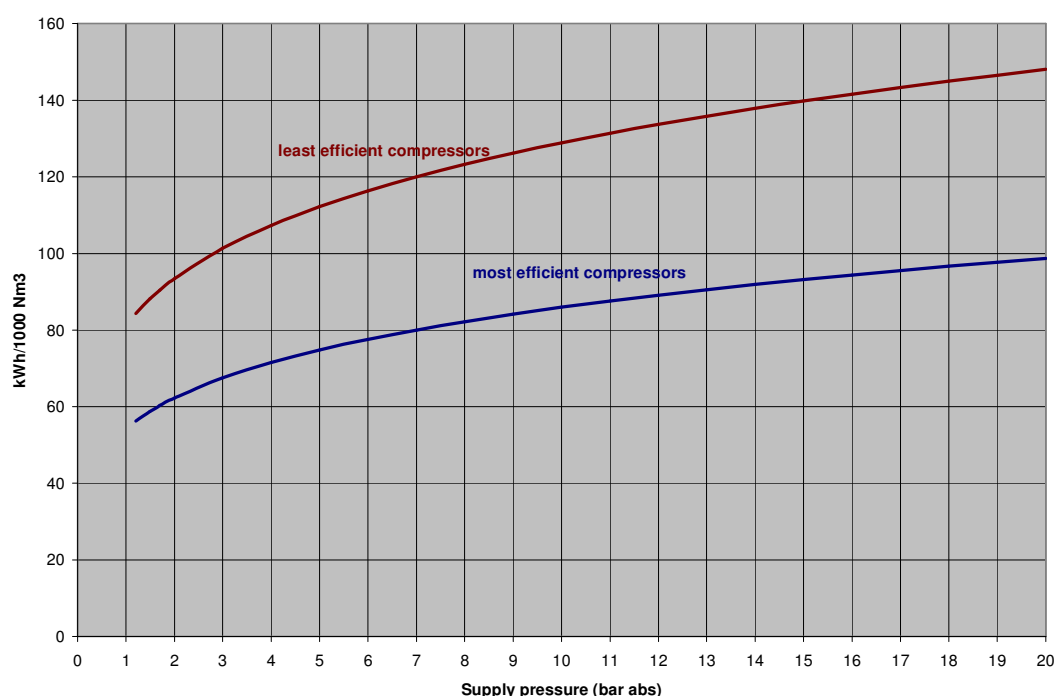
If it is not yet known, you should determine what energy use and energy costs are involved with your compressed air supply.

With the methodology described in Best Practice 2 you can quantify the electricity use in kWh per Nm³ (or kWh per 1,000 Nm³) of compressed air. This is the most important Energy Performance Indicator to use with compressed air energy efficiency measures. See for an explanation of energy performance indicators the chapter 8.3. in Best Practice 2.

The amount of energy required to produce say 1,000 Nm³ compressed air depends upon the type of compressor and its efficiency, and the air supply pressure. The quantity of compressed air is often expressed in Normal cubic metres (Nm³). This is a standard volume at 1.013 bar pressure and 0°C temperature.

Figure 20 gives an indicative range of electricity consumption per 1,000 Nm³ for compressors as a function of air supply pressure.

FIGURE 20. ELECTRICITY CONSUMPTION PER 1,000 NM³ COMPRESSED AIR



As can be seen there is an energy (and costs) incentive to work with lower air pressures. Knowing the energy and costs involved in compressed air production is the basis for creating awareness of energy efficiency improvement in this field.

BP 5 5. Opportunities to Reduce the Compressed Air Consumption

BP 5 5.1. Consider Alternatives to the Use of Compressed Air

Alternatives are often more energy efficient. Examples of potentially inappropriate use of compressed air are:

- Open blowing: Compressed air is used with an open unregulated tube or pipe for: cooling, drying, clean-up, cleaning conveyors, etc. This use can often be avoided by using alternatives.
- Using compressed air for aspirating, atomising and padding, etc. In most of these cases, a more efficient low-pressure blower could be used.
- Using compressed air for material handling. In addition, in this case a low pressure blower could be an alternative.
- Using compressed air for vacuum generation. In this application compressed air is used in conjunction with an ejector to create vacuum for all types of handling. Vacuum generators can cause serious peak loads in compressed air demand, causing inefficiencies in compressor operation. For more base load vacuum generation (operating more than 30% of the time) an alternative could be to use a dedicated vacuum pump, which is more efficient, and is often more reliable in creating the appropriate vacuum conditions.
- Using compressed air in open hand-held blowguns or lances. Do not use, also for safety reasons, unregulated hand-held blowing devices. Only blowguns that comply with the safety standards should be used, and their use should be limited to where it is really necessary.
- Using air tools instead of more efficient electrical tools.
- Unregulated end use. A pressure regulator should be placed in the distribution system close to the end user to maximise the end use pressure, otherwise it uses full system pressure, which is a potential cause for dynamic pressure problems in the system and can introduce substantial inefficiencies in compressor operation.

BP 5 5.2. Detect and Repair Leakages

Detection of leaks can be done during plant shut down hours when you can hear leakages. Detection with an ultra sonic acoustic detector is also a cost effective method, which can be used during operation. If not taken care of, a substantial part (20% or more) of the produced compressed air can be wasted through leaks. The most common leakage areas are: couplings, hoses, tubes, fittings, pipe joints, quick disconnectors, condensate traps, and end user devices.

BP 5 5.3. Use More Air Efficient Equipment

- Compressed air is often used for cooling, drying and cleaning. Use efficient nozzles and regularly service blowing nozzles to save compressed air.
- Check the useful life of each end-use application. A worn tool will often consume an excessive amount of compressed air, and can affect other operations nearby.
- Check with suppliers whether manufacturing processes can be reconfigured to improve efficiency.

BP 5 5.4. Optimising Compressed Air Supply

The main areas for optimisation are:

- Controlling air compressor operation (i.e. load control of individual compressors).
- Keeping air pressure at minimum required level.
- Regular servicing and maintaining air system components.

BP 5 5.5. Optimise Air Compressor Operation

Compressor operation is aiming at matching supply and demand at a stable system air pressure under all load variations. How efficient this can be done depends upon the type of compressors installed, the type of load control, and the demand pattern of the compressed air users. So optimising the compressor operations has all to do with controls, storage, and demand management.

A) Storage

High volume intermittent air demand would cause air pressure fluctuations and consequently heavily fluctuating compressor operation. These demand fluctuations can be dampened by dedicated air storage vessels in the distribution system as close as possible to the intermittent consumers, enabling the compressors to run at a more flat load profile. The required storage volume is a function of the intermittent air demand (m^3/min) over time and the allowable pressure drop in the compressed air system. The following formula can be used to estimate the required storage volume:

$$V_s = v_i \times t / (\Delta p)$$

Where:

V_s = Volume storage vessel (m^3)

v_i = intermittent air consumption (m^3/min)

t = duration of intermittent consumption (min)

Δp = permissible pressure drop (bar)

B) Compressor load control

Usually compressed air systems use multiple compressors. On an annual average basis they all operate in part load, because the available capacity is based upon serving the peak demand (often in a (n-1) concept, meaning that always one compressor is in stand-by function). So the individual compressors all operate with a form of capacity control. Compressors can have different types of load control:

- Start/stop, the capacity control cycle consists of running the compressor at full capacity and shutting it down.
- Load/idle running, the compressor is running continuously and the capacity is controlled by loading and unloading the suction side so that it does not deliver air for a period of time.
- Part load operation, the compressor is running continuously and has a modulating suction side capacity control.
- Variable speed control, the compressor has a continuous capacity control by varying the compressor speed.

Variable speed control is the most efficient form of load control. With the other types, the idle running can still require 25% to 30% of the full load electricity. What type of control is applicable for your compressors depends upon the types you are using.

With multiple compressors in operation, you should optimise the combined compressor production profile to minimise the overall electricity consumption. This can be achieved with a master control that manages the load sharing and running hours of all compressors.

BP 5 5.6. Keeping Air Pressure at Minimum Required Level

As described before a lower air pressure will significantly reduce the required electrical power of the compressors.

- If your air supply pressure is dictated by a relative small quantity of air at a higher pressure, you can consider installing a booster compressor for that specific quantity and run the total system at a lower pressure.
- If your system pressure needs to be high in order to cope with high intermittent air demands, you can consider installing extra storage vessels close to these intermittent users to enable reducing your system pressure and the pressure fluctuations in your system.

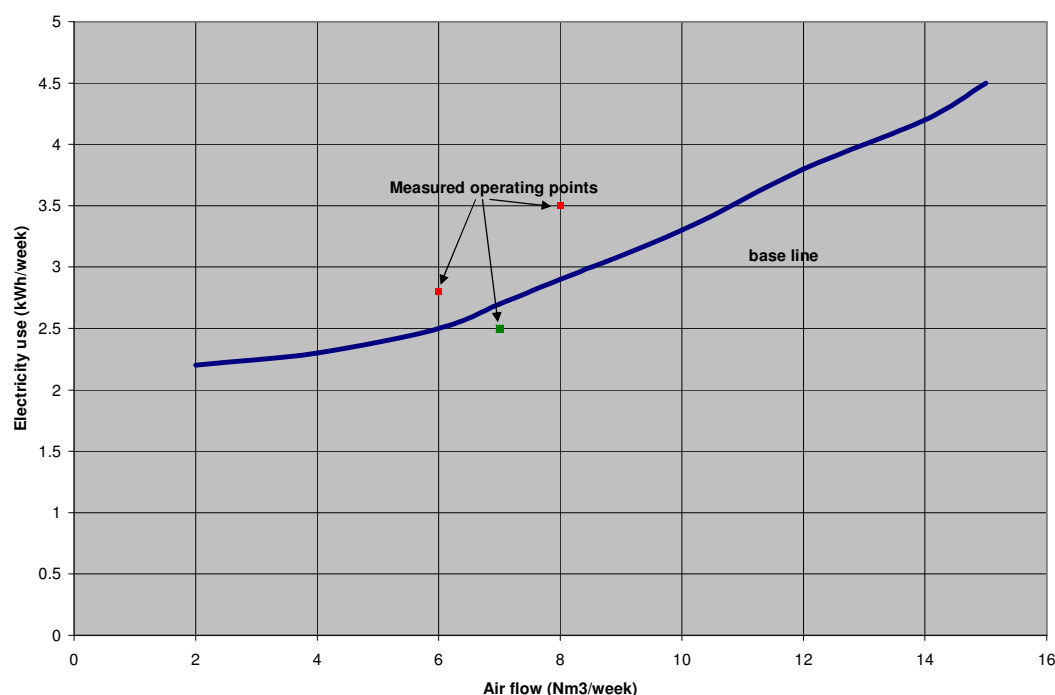
BP 5 5.7. Regular Servicing and Maintenance of Air System Components

Compressed air systems require regular inspection and periodic maintenance to keep components in a good condition. It requires caring for the equipment, and responding promptly to changes and trends in the operations and efficiencies. This will enable the

system to operate with a high reliability. Inadequate maintenance and lack of regular inspections can increase energy consumption via lower compression efficiency, air leakages, etc. It also can lead to higher air operating temperatures and consequently poor moisture control in the dryers.

- Establish a regular, well-organised inspection and maintenance programme in accordance with the manufacturer's specifications. You should evaluate whether more frequent inspection, for example with filters and coolers, are necessary to optimise system efficiency.
- Measure pressure drop across air treatment components such as filters, coolers and dryers. Clean or replace filters if pressure drop exceeds 0.5 bar.
- Measure dryer inlet temperature. This should not exceed the recommended level for your type of dryers with the compressor at full load. If this temperature is too high check the after cooler and clean heat exchanger if necessary.
- A good way to check whether your compressed air system is operating efficiently is to develop a base line for the weekly electricity use for compressed air (kWh/week) against the weekly air production (Nm³/week) and regularly plot the weekly results in this graph to check how the performance relates to the base line. An example is given in Figure 21.

FIGURE 21. COMPRESSED AIR OPERATING PERFORMANCE



BP 5 6. Other Energy Savings Options in a Compressed Air System

- Air intake from a cold location: The lower the air intake temperature the less power is required for the compressor to compress the air to the required pressure. If air compressors are located in a building, you should consider ducting the intake to outside the building and take colder outside air.
- Regularly check the condition of the inlet filters: Dirty or even blocked filters reduce the airflow and increase the power required per m³ of air.
- Utilise the cooling heat from the compressor and after cooler: Almost 90% of the energy input to the compression cycle is converted into heat that must be removed. This heat can be used to generate low temperature heat (in the order of 50 to 70 °C hot water). Some compressor types use the heat in the hot compressor discharged air for regeneration of the dryers.

BP 5 7. List of recommended measures

Good Housekeeping measures to reduce energy use of your compressed air system are listed below:

- Check the system regularly for leaks and repair leaks.
- Check for unnecessary and inappropriate use of compressed air, and make a checklist of users.
- Replace worn out air devices (such as spray nozzles).
- Set the pressure in the system at the minimum acceptable level taking into account the demand profile and the volume of storage vessels.
- Investigated whether boosting for small consumers, requiring high pressure, make sense to reduce the system pressure
- Check the capacity of the storage vessels in relation to consumption pattern in order to optimise air compressor energy consumption.
- Check the temperature of the incoming air does not exceed the specified value for he dryers, and check whether the dryers operate correctly.
- Consider improvements in measuring air pressures and volume in the system.
- Measure air compressor energy use and relate it to produced air volume.
- Develop the optimal load sharing for multiple compressors in order to minimise electricity use.
- Investigate the utilisation of compressor cooling energy.
- Check the regular inspection and servicing of compressed air equipment with regular replacement of filters.

You can find an additional list of useful measures below, which might also go beyond mere “good housekeeping”.

Compressed Air

Low-cost / short term opportunities	
Energy Saving Opportunity	Action to Check
1. Switch off whenever possible.	-
2. Install low-cost solenoid valves on air supply lines to individual machines. Switch off compressed air supply as soon as machine is switched off.	-
3. Clean air intake filters regularly	-
4. Use lowest possible operating pressure. Reduce pressure locally if possible.	-
5. Use lowest air intake temperature possible.	-
6. Fit 2-speed motors.	-
7. Fix leaks	-
8. Check on correct pressure setting regularly.	-

Higher cost / longer term opportunities	
Energy Saving Opportunity	Action to Check
1. Fit a small (jockey) compressor to meet off-peak demand.	-
2. Duct air intake to ensure coolest possible.	-
3. Fit air flow and kWh meters to monitor power and air use.	-
4. Install modern controls on multi-compressor installations.	-
5. Fit a standard heat recovery unit.	-
6. Air pre-cooling.	-
7. If <u>some</u> users are using low pressure air (2.5 - 3 bar), install two separate systems.	-
8. Use frequency control for compressor.	-
9. Use an individual compressed air supply for special applications.	-
10. Replace pneumatic tools by electrical tools	-

Source: www.bess-project.info

BP 5 8. Further information

Best Practice Example How to Reduce Energy Use in Your Compressed Air System

An SME in the chemical sector has a compressed air pressure at generation point which exceeds 8.5 bar, however the highest required pressure from the production lines is 6.5 bar.

It is therefore a logic step to reduce the pressure, which does not even require additional investment. A reduction of 1 bar can lead to yearly energy savings of more than €14 000 or almost 300 MWh. Energy and cost savings can be that easy!

BP 5 8.1. Additional reading

1. Compressed air, Introducing energy savings opportunities for business, Carbon Trust publication CTV017, Technology Overview
www.carbontrust.co.uk
2. Improving Compressed Air System Performance, a Sourcebook for Industry, US DOE Office of EERE publication and many other information sources
http://www.eere.energy.gov/industry/bestpractices/compressed_air.html

Best Practice 6 How to Reduce the Energy Use in Your Buildings

BP 6 1. Introduction

Usually there is considerable scope for reducing energy consumption in buildings. Energy savings in these areas directly contribute to raising your net profits.

- Heating Ventilation and Air Conditioning (HVAC) accounts for the majority of the energy use in buildings and is therefore a key area to target for energy efficiency measures. Overheating in winter and over cooling in summer are the main causes of wasting energy.
- The second important category is the use of electricity in buildings, for lighting and in office facilities.

BP 6 2. Measuring and Trending Energy Use in Buildings

To monitor the energy use in buildings and assess the savings you have achieved with energy efficiency measures, you must be able to measure and record the electricity consumption and heat or fuel consumption of the buildings. Check whether that is being done and if not what is required to do so.

Check what historical information on energy consumption is available and if this information is sufficient to develop a 'base line' for your energy efficiency measures.

BP 6 3. Influencing Factors and Performance Indicators

In the Best Practice 2, the use of energy performance indicators has been described. The factors that influence the energy use in buildings are the ambient conditions, the required inside comfort levels, the internal heat load, and the building characteristics. The ambient conditions have a large impact on the energy use (both heating and cooling) without you being able to influence them. Therefore, in order to make meaningful assessments of your energy use in buildings, you should neutralise the influence of ambient conditions. This can be done with the degree days method. Degree days are a measure for the severity and duration of cold weather and hot weather. In essence, it is a summation over time (normally a month) of the differential between the daily average outside temperature and a reference inside temperature (often 18°C). You can distinguish heating degree days (HDDs), they are counted when the outside temperature is below the reference inside temperature and cooling degree days (CDD), when the outside temperature is above the reference temperature. The colder the weather in a month the higher the HDD number will be.

So good performance indicators for the energy consumption of buildings are:

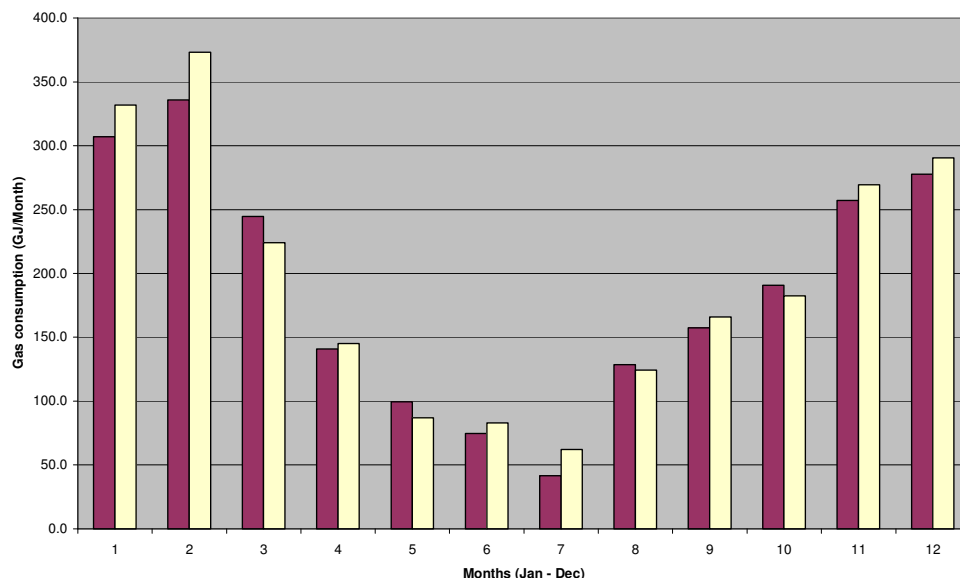
- The energy use during the heating season in relation to HDDs. Depending on your heating system this will monitor fuel consumption or hot water use, plus electricity consumption.
- The energy use during the cooling season in relation to CDDs. This will commonly be monitoring mainly electricity consumption as most cooling units consume electricity.
- The base load energy use. Often in spring and autumn there is a period that requires no heating and cooling. This period can be used to analyse the base-load electricity use in your buildings.
- The energy consumption (both electricity and heat) of buildings during the unoccupied hours. This can be an indication for unnecessary energy use. You should be able to trace the usefulness of this energy use.

BP 6 4. Working with Degree Days

An example of working with degree days is given in Figures 22 and 23. Figure 24 gives the gas consumption per month for heating a building for two consecutive years. From this figure you can only conclude that colder months need more fuel but it is not clear why for the same

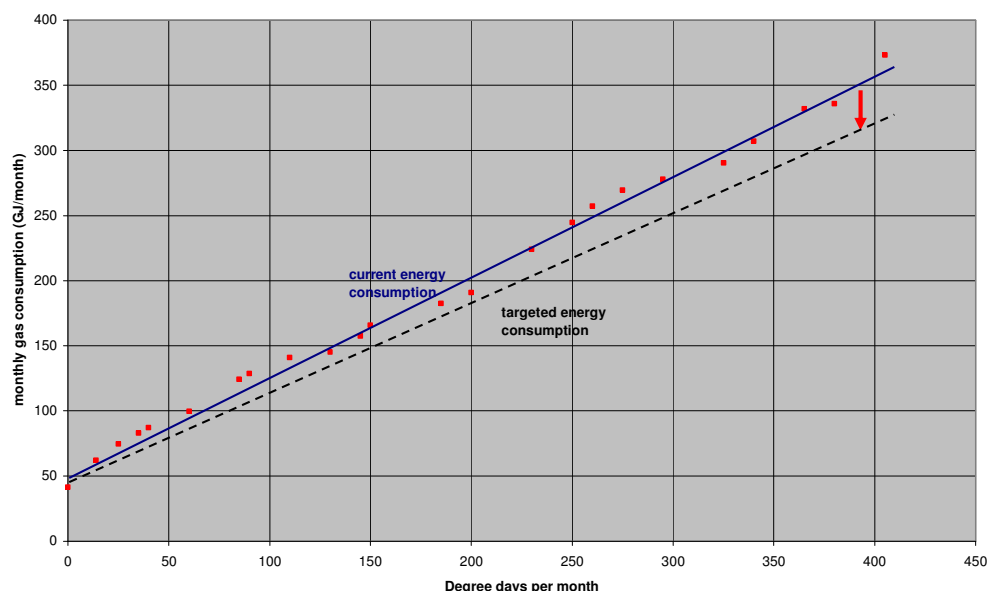
month sometimes year 1 needed more fuel and sometimes year 2. Furthermore, it is not clear what the benchmark value for this building should be.

FIGURE 22. GAS CONSUMPTION FOR HEATING PER MONTH



In Figure 23, the gas consumption for each month is plotted against the heating degree days for that month. Here you can see that there is a reasonable relationship. The blue line is the current relationship; the dotted line can be used for target setting of energy savings measures in your building.

FIGURE 23. EXAMPLE OF DEGREE DAYS METHOD (FOR HEATING DEGREE DAYS)



Most EU countries provide degree days information. To use this method, check whether data is available in your country. If that is not the case, you can develop your own degree days information as long as you have the information available of the daily average outside temperatures.

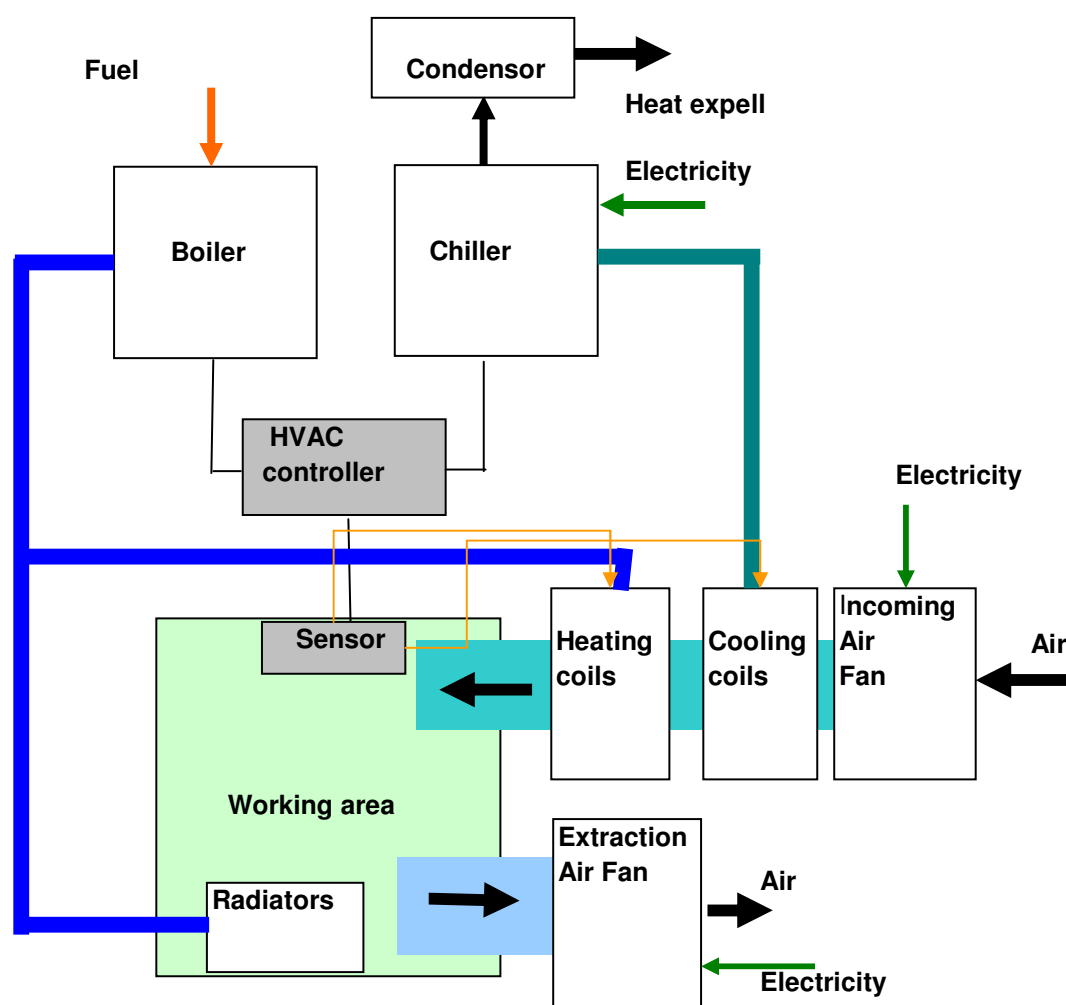
A less accurate compromise approach – if no degree days information is available - would be to work with weekly or month average ambient temperatures in relation to a reference inside

temperature. It can be useful to check Eurostat, the European Commission statistical service, which is offering statistics on degree days for free. (<http://epp.eurostat.ec.europa.eu/portal/page/portal/energy/data/database>)

BP 6 5. HVAC

HVAC systems are designed to regulate the climate inside buildings by compensating for heat loss and too much heat input and by providing sufficient fresh air. HVAC systems vary widely in terms of system set up, from just heating in winter with a hot water boiler and radiators placed in the rooms to a full air conditioning system including heating, cooling and humidifying areas.

FIGURE 24. BASIC SCHEME OF AN HVAC SYSTEM



You should start your energy efficiency actions with understanding and assessing the HVAC systems in place to determine:

- their type and function,
- their technical quality,
- the present way of operation and how they are being controlled, and,
- the status of maintenance and servicing.

It is worthwhile, for a good understanding, to have a basic Process Flow Scheme of the HVAC systems, such as you can see in Figure 24 above.

Four important factors determine the energy use of your HVAC systems:

- The required indoor air condition.
- The internal heat development (such as from lighting and equipment).
- The design, lay out and insulation quality of the building.
- The technical quality of the HVAC equipment and how they are being maintained.

With all four factors, you can assess what scope there is for energy efficiency improvement in your building.

BP 6 5.1. Define and, If Possible, Reduce the Need for HVAC

You should start your energy efficiency activities with checking what conditions are really needed in different process areas, storage rooms, staff working areas, etc. to determine the starting points for your HVAC systems. The type of HVAC system and how it is used has a big impact on the energy consumption. Especially cooling and humidifying can require a lot of energy. So you should critically investigate the need for HVAC and whether there are alternatives for air conditioning systems.

BP 6 5.2. Assess Your Current HVAC Systems

Then, next, you should investigate to what extent your HVAC systems are designed to comply with the starting points and where adaptations would be necessary. With this information, you can develop your business case for the necessary changes and plan these actions. In parallel, you can start with investigating what possible Good Housekeeping (GHK) measures can be applied to improve the present system and the present operation. A list of possible GHK measures is given at the end of this Best Practice.

BP 6 5.3. Habits and Comfort Levels

Changing people's habits can often to a large extent contribute to improving energy efficiency and reducing energy costs. It is, therefore, important to raise awareness of how every one can influence the need for energy. There are all kinds of positive and creative actions that you can use to enhance and sustain energy efficiency awareness.

BP 6 5.4. Maintenance Issues

- A poorly maintained boiler can use over 10 % more fuel than needed. So you should have your boilers serviced at least once per year by a qualified service company. With each service activity a combustion tuning should be performed and the boiler heat exchanger surfaces and burner unit should be cleaned.
- The same applies to your air conditioning systems. Ensure that they are correctly maintained.
- Check control settings of HVAC equipment and settings of thermostats and timers, and reset drifted control set points.
- Keep evaporators of air conditioning units free of ice and clean condenser coils.
- Replace and clean filters and make sure dampers in the air duct system can move freely.
- Ensure hot and cold air ducts are well insulated and do not leak. Clean air ducts regularly. Over time ducts may get fouled causing not only deterioration of air quality, but also extra resistance reducing the capacity of the air fan.
- Regularly check radiators for air ingress into the hot water system and 'bleed' radiators when necessary.
- Regularly clean all heat transfer surfaces and keep them unobstructed.
- Close the cooling air inlets to air conditioning units in winter, as this prevents unnecessary cold air entering through these inlets.

BP 6 5.5. Optimise Operation

- Review air conditioning settings (thermostats and timers) against building occupancy and check whether adjustments can be made for hours that the building is not occupied.
- Check whether distinction can be made in the heating conditions for specific areas, such as for example storage areas that do not need to be warmed to the same level as

occupied areas.

- Consider installing self-regulating controls for the ventilation systems to shut down the system during overnight.
- Interconnect the controls of separate space heating and cooling units to prevent simultaneous heating and cooling.
- Consider using thermostats with timer settings to switch heaters on and off in parallel to shift operations in order to avoid heaters left on while shift operation is ended.
- Use outdoor temperature measurement to trim the set point of hot water supply temperature to radiators and heating coils. Compared to mid winter heat demand water temperatures in spring and autumn can be much lower, saving fuel in your boiler. This can be achieved by using the outdoor temperature measurement to control the set point of the hot water supply temperature.

BP 6 5.6. Minimise Building Heat Losses

This can be achieved by:

- Improving building insulation.
- Repairing broken windows.
- Upgrading windows to double or triple glassed windows.
- Avoiding cold draughts.
- Consider self closing dampers on the air intake and the discharge of extraction fans to prevent back draught into the building when the equipment is off.

BP 6 5.7. Minimise Excess Heat Development in Building Areas

- Improve building insulation and use outside solar shading.
- Reduce lighting where possible and shut off unnecessary lighting.
- Consider increased use of daylight where possible.
- Insulate heat generating equipment.

BP 6 5.8. Heat Recovery Issues and Other Energy Savings Options

1) Check whether it is possible to reduce the energy for conditioning incoming air by recovering some energy (warm and cold) from the extracted air to pre-treat the incoming air. Types of heat recovery technologies that you can consider are:

- Recirculation of part of the extraction air: Partial recirculation is cost-effective if you are heating the air and exhaust air is warmer than the incoming air. The same applies for cooling. This is only possible when the exhaust air quality is sufficient.
- Heat recovery wheel: Heat or cold is recuperated from the exhaust air and transferred to the incoming air with a rotating heat exchanger.
- Heat pipe system: An intermittent fluid is used to transfer energy from exhaust to intake.
- Stationary air-to-air heat exchangers.
- Water/glycol heat transfer loop to transfer heat from exhaust to intake air.
- Heat pump based systems: Exhaust heat is 'pumped up' to a higher temperature level for re-use.

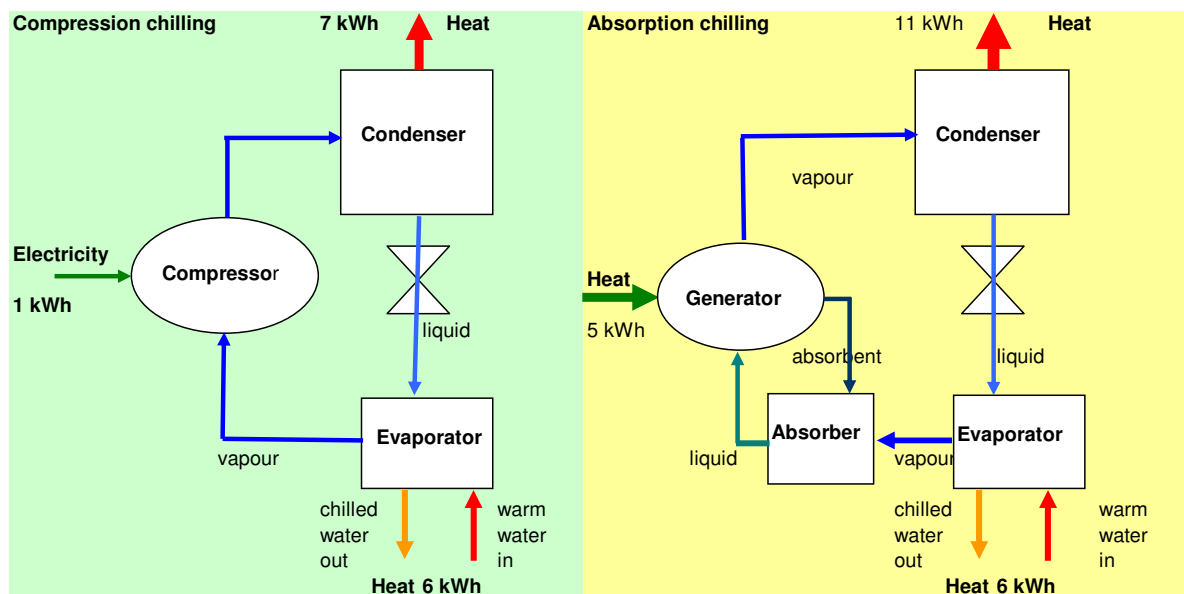
Each alternative has its specific pro's and con's and should be evaluated against your specific conditions.

2) Check whether electric resistance heaters are being used and if so re-consider the need for it. Try solving the comfort problem to avoid the use of these types of energy wasting heaters. If they are unavoidable, provide them with a timer to switch off automatically when not needed.

3) You can consider also the use of alternative heat sources such as solar energy, and, if available at your site the use of ground water heat pump systems.

- 4) Consider using absorption chilling units. Most chillers are compression chilling units. They use an electrical driven compressor to transport the heat that is taken in by the evaporator to the condenser, where it is emitted to the environment (see Figure 25 for a simplified scheme).

FIGURE 25. COMPRESSION AND ABSORPTION CHILLING UNITS



If you have a waste heat quantity at a temperature above 95°C available at your site in the form of hot water or low pressure steam, you can consider using an absorption chilling unit instead of a compressor chilling unit for your base load chilling duty. In that case, you would save on electricity consumption and use free energy to drive the absorption chiller.

The essential difference with a compressor chilling unit is shown in Figure 25. The absorption chilling unit uses an absorbent (commonly a lithium-bromide/water solution) to absorb the heat (in the form of low pressure water vapour) from the evaporator. From the absorber the liquid is pumped to the generator, where the waste heat is used to boiler out the water vapour from the absorbent. The water vapour flows to the condenser, where it is condensed and the condensation heat is emitted into the atmosphere. The concentrated absorbent flows back from the generator to the absorber, and the condensed water is led down in pressure and flows back to the evaporator to pick up the heat from the warm incoming water.

The efficiency of a chilling unit is expressed by its “coefficient of performance” (COP). This is the amount of heat that can be removed by the chiller per unit of work. So a COP of 6 for a compressor chilling unit means that per kWh electricity input into the compressor 6 kWh of heat can be removed in the evaporator from the chilled water (see Figure 25). Compression chilling units are more efficient than absorption chilling units (typically: COP 6 for compression and COP 1.2 for absorption). For a comparable cooling load, absorption chillers are larger and need more cooling water for the condenser. Also, their investment is higher. So their typical application is for base load cooling duty where free waste heat is available.

BP 6 6. Use of Electricity - Lighting and Office Equipment

There are many ways to reduce the energy consumption associated with lighting without compromising comfort levels. Key areas to look at are:

- What type of lighting is presently used in the building?
 - Are standard incandescent light bulbs being used? These are very inefficient and should be replaced by compact fluorescent (gas-discharge) bulbs, which use up to 75% less electricity.

- What types of fluorescent tubes are in use? If you still use the conventional fluorescent tubes, consider the installation of high frequency fluorescent lighting, which are approximately 25 to 30% more efficient and eliminate flicker.
- Are lamps, fittings and roof lights clean?
 - They should regularly be clean to restore the lighting levels in the areas.
- Is the exterior lighting always switched off when it is not needed?
 - Exterior lighting should be limited to the hours of darkness. Consider installation of presence detection switches for unattended places in the process areas.
- Are banks of lights grouped over more switches.
 - Splitting banks of lights over more switches will increase your control over lighting use.

BP 6 6.1. Other Electricity Use in the Office

Office equipment such as computers and photocopiers are integral parts of the daily activities. You should however be aware of how much energy they can consume. There are some rules to control the energy use of this equipment:

- Is the built-in energy savings mode of computer activated?
- Are computers and monitors switched off during overnight?
- Avoid photocopiers being placed in air conditioned areas.
- Are photocopiers switched off overnight?

With these simple measures you can substantially reduce your electricity consumption and also the heat gain and consequently the cooling duty of your buildings.

BP 6 7. List of recommended measures

The following checklist gives the range of Good Housekeeping Measures that can reduce your energy use in your buildings.

HVAC System

- Ensure regular inspection and servicing of heaters/boilers and air conditioning equipment
- Ensure that air fans, and air ducts are cleaned and filters are replaced regularly.
- Ensure that evaporators and condensers of air conditioning units are clean and well maintained
- Determine minimum heating requirements for individual areas in buildings and ensure that room thermostats work with the correct set points for climate control (heating, cooling, humidifying)
- Ensure timers of thermostats are working, and on the correct setting
- Where appropriate consider installation of thermostat valves on radiators
- Consider energy conservation measure such as insulation, and outside sunlight shading
- Shut off unnecessary heating elements
- Repair broken windows
- Ensure boiler controls are working, and at the correct settings
- Remove any obstructions in front of radiators or heaters
- Avoid heaters and air conditioning units operating simultaneously in the same space ¹⁾
- Check whether there are complains about room temperatures (too high when heated, too cold when air conditioning on)
- Check whether there portable electric heaters in use ²⁾
- Check how hot water is being provided ³⁾
- Check if windows and doors are closed when heating or air conditioning is on
- Check for any cold draughts coming from windows or doors

Lighting

- Switch off lights when rooms are not in use
- Switch off lights when daylight is sufficient
- Clean lamps, fittings and roof lights
- Replace traditional incandescent light bulbs by compact fluorescent bulbs
- Consider use of high frequency fluorescent lighting where appropriate
- Limit exterior lighting to hours of darkness
- Keep exterior lighting at unattended places to a minimum, where appropriate use presence detection switches to switch on these lights
- Consider partition of banks of lighting by individual switches
- Use presence detection switches to switch on lights

Use of electricity (motors, pumps, fans, etc)

- Switch off equipment when not needed
- Consider installation of high efficiency motors
- Checked where variable speed can be applied

Use of electricity in the office

- Put computers in energy saving mode when not in use
- Switch off monitors when not in use

Remarks:

- 1) This should be avoided as it is a waste of energy. To avoid this happening set a dead band of 5°C between heating and cooling.
- 2) Use of portal electric heaters can be expensive. Check whether they can be avoided, and if they are needed provide them with a time switch so they turn themselves off after a certain time.
- 3) Consider installing local water heaters where small quantities are required instead of supply from the central system. Insulate all hot water tanks and piping unless.

Below you can find an alternative list of energy saving opportunities in your building, which might also go beyond mere "good housekeeping".

Heat Utilisation for your space heating

Low-cost / short term opportunities	
Energy Saving Opportunity	Action to Check
1. Use heat only when area is occupied	-
2. Set thermostats to minimum for comfort	-
3. Minimise loss of hot air	-
4. Clean and effective heaters	-
5. Maintain pipe insulation in unheated areas	-
6. Check condensate traps	-
7. Vent air from hot water systems	-
8. Time switches	-
9. Manual controls where appropriate	-
Higher cost / longer term opportunities	
Energy Saving Opportunity	Action to Check
1. Install more/more efficient thermostats	-
2. Use motorized valves to divide building into different zones	-
3. Air curtains	-
4. Change energy source	-
5. Change heating system where: <u>Insulation</u> <u>Ventilation</u> <u>Use</u> Good High Radiant Heat Poor Low Convective Heat	
6. Improve building insulation	-

Lighting

Energy Saving Opportunity	Action to Check
1. Use the most efficient lamps consistent with required illumination levels and colour rendering.	-
2. Use the light output from lamps efficiently.	-
3. Maintain lamps and fixtures clear of light-blocking dust and dirt.	-
4. Switch off lights where lighting is not needed.	-
5. Consider automatic control of lighting (time clocks and/or photo cells).	-
6. Make the best use of daylight.	-
7. Avoid the absorption of light by the surroundings (light-coloured wall, ceilings, and floors).	-
8. Replace lamps which have exceeded their rated life.	-
9. Use "switch-off" and "save-it" stickers as a tool of good housekeeping.	-
10. Consider new technologies in order to reduce installation cost, such as infrared switching.	-
11. Divide the lighting system of a large space into several independent lighting groups.	-
12. Use presence detection switches	-
13. Use a lighting system that is continuously variable (e.g. high-frequency fluorescent lighting).	-

Building skin

Low-cost / short term opportunities	
Energy Saving Opportunity	Action to Check
-	-
Higher cost / longer term opportunities	
Energy Saving Opportunity	Action to Check
1. Thermal insulation of floor	-
2. Thermal insulation of walls	-
3. Thermal insulation of roof	-
4. Use of double-glazed or solar shading glass windows	-

Air-conditioning

Low-cost / short term opportunities	
Energy Saving Opportunity	Action to Check
-	-
Higher cost / longer term opportunities	
Energy Saving Opportunity	Action to Check
1. Use thermal energy storage systems (i.e. ice banks)	-
2. Use shading devices for windows.	-

Central Heating

Low-cost / short term opportunities	
Energy Saving Opportunity	Action to Check
1. Use a weather dependent control to regulate the temperature of the boiler water in relation to the outside temperature.	-
2. Install an advanced timer for the boiler operation schedule.	-
3. Insulate pipework	-
4. Insulate hot water storage tanks	-
Higher cost / longer term opportunities	
Energy Saving Opportunity	Action to Check
1. Divide large interior spaces into smaller areas.	-
2. Use radiation heating in cases where large ventilation rates are required.	-
3. Use displacement ventilation in the case where the heated indoor areas are higher than 6 meters.	-

Ventilation system

Low-cost / short term opportunities	
Energy Saving Opportunity	Action to Check
-	-
Higher cost / longer term opportunities	
Energy Saving Opportunity	Action to Check
1. Heat recovery of exhaust air using a rotary wheel.	
2. Reduce the amount of ventilation air as much as possible by the installation of: ▪ Timer switch; ▪ Occupancy sensor ▪ Air quality; ▪ Frequency control on the fan motor	
3. Prevent infiltration through door openings with: ▪ Thermal insulation ▪ Draught curtains ▪ Air cushion ▪ Automatic door ▪ Slip door ▪ Rubber seal between door and doorpost instead of brushes or no sealing.	

Source: www.bess-project.info

BP 6 8. Further Information

Best Practice How to Reduce the Energy Use in Your Buildings

In premises with well controlled systems, heating bills can be 15-35% lower than in poorly controlled buildings. Likewise, making use of daylight can reduce lighting cost by 19% in a typical office. In conjunction with staff action, the use of automatic controls can ensure these savings are achieved. (Carbon Trust)

For example one of the CARE+ audited companies uses special lamps and reduces lightning at factory boundaries, where working areas are not affected. This led to energy savings on lighting of 50%.

BP 6 8.1. Additional reading**1. Carbon Trust www.carbontrust.co.uk****Examples**

- a. Heating, ventilation and air conditioning, saving energy without compromising comfort, CTV003,
- b. Lighting technology overview CTV021
- c. Energy Saving Fact Sheet Air conditioning, GIL120
- d. Energy Saving Fact Sheet Ventilation, GIL130
- e. How to maintain your heating system, GIL156
- f. Assessing the energy use in your building, CTL 003
- g. Degree days for energy management, CTG 004

2. Degree days: Eurostat website

<http://epp.eurostat.ec.europa.eu/portal/page/portal/energy/data/database>

Best Practice 7 How to Improve Energy Efficiency With Your Motors And Drives

BP 7 1. Introduction

In the chemical industry, motors and drive systems are being used for all sorts of fluid transportation and material handling movements. This requires a relatively large portion of the total energy use (mainly electricity) in the chemical industry. Therefore, exploring the potential for energy performance improvements makes perfect business sense as it can result in quite substantial costs savings.

To investigate the potential for energy savings not only the motor or driver itself should be looked at but the complete drive application, including the driven equipment and at what process conditions the system has to work.

By far the most widely used type of drive in the chemical industry (and industry in general) is the Alternating Current (AC) squirrel-case induction electric motor. This type of motor is favoured because of its relatively low investment, its high reliability and availability, and its low maintenance. Other electric motor types, such as the Direct Current (DC) motor, are used in special applications. This Best Practice concentrates on what energy efficiency measures can be taken in using the AC induction motor. Other drivers such as the reciprocating combustion engine or the back-pressure steam turbine are not covered in this Best Practice because they are not used commonly in chemical SMEs.

This Best Practice describes a number of energy efficiency improvement options that you may consider for your particular plant. These are:

- The benefits of a motor management programme and how to arrange it;
- Repair or replace decisions;
- Measures to mitigate inefficiencies in oversized driving systems;
- The benefits of high efficient motors;
- Variable speed drives (VSD) options and their benefits;
- How to improve the in-plant power distribution system;
- A number of good housekeeping measures for drive systems.

BP 7 2. AC Electric Motor Operating Characteristics

In the AC induction motor a rotating magnetic field is created in the stator by the AC current supplied to the stator windings. The rotating magnetic field induces currents in the rotor conductors, and these in turn create the rotor magnetic field. The magnetic field in the rotor follows the stator magnetic field and thus creates a rotating torque that drives the connected equipment. There are two types of induction motors. One is called an asynchronous electric motor (or a slip motor), because the rotor speed is slightly below the speed of the supplied power. There are also synchronous motors, such as the permanent magnet motor. This motor type uses permanent magnets in the rotor, which track the stator rotating magnetic field exactly at synchronous speed. Basically, the speed of the induction motor is determined by the frequency of the supplied AC power (in Europe 50 Hz), and the number of motor poles, and to a lesser extend also the motor load. A motor with 4 poles rotates at half the speed of a two pole motor.

The most important operating characteristics determining the electric motor selection are: the power to be supplied; the required rotor speed; the required torque; and the supply voltage. The motor efficiency changes with the load. It is rather stable between 70 and 80% load and drops slightly from 80% to full load and from 70% to 50% load. Below 50% load efficiency begins to deteriorate significantly. The speed of an AC induction electric motor depends on the grid frequency (50 Hz), the number of poles, and the slip characteristic between the stator and rotor magnetic fields (full load slip can vary between < 1% to 5%). Common

synchronous speeds are: 3,000 rpm (2 poles); 1,500 rpm (4 poles); 1,000 rpm (6 poles); and 750 rpm (8 poles).

However, many applications require speeds different from these standard speeds. Therefore, the motor and the motor-driven equipment are usually connected through a speed adjustment device, such as a gearbox, a belt, or a variable speed drive. The latter may be an eddy current coupling, a hydraulic coupling or an electronic Variable Speed Drive (VSD). The electric motor itself can also be executed as multiple speed motor by using separate windings within the same stator or by an external switch that can change the number of poles.

The supply system should be sufficiently robust to supply the required current while keeping the supply voltage at the acceptable level. Motor performance is significantly affected when it operates at voltages +/- 10 % or more from its rated voltage.

BP 7 3. Motor Efficiency Classes and Policy Measures for Electric Motors in the EU

In recent years, high efficient (HE) AC electric motors have come on the market which offer substantial energy savings at reasonable investment costs. For the power range up to 90 kW the European Commission and CEMEP, European Committee of Manufacturers of Electrical Machines and Power Electronics (the European motors trade association) have agreed on a motor efficiency classification scheme, which distinguishes three categories of efficiency, known as EFF1, EFF2, and EFF3 applicable to 2-pole and 4-pole motors. All manufacturers who have signed the agreement will use the applicable efficiency logo on their motors, enabling an easy identification of the efficiency class of the motor.

Table 18 shows the efficiency classes. The efficiencies apply to design load and 75% load for totally enclosed fan cooled (IP 54 or IP 55) three phase AC squirrel case induction motors.

TABLE 18. EU ELECTRIC MOTOR EFFICIENCY CLASSES

kW	EFF3 2- & 4-pole (%)	EFF2 2- & 4-pole (%)	EFF1 2-pole (%)	EFF1 4-pole (%)
1.1	< 76.2	≥ 76.2	≥ 82.2	≥ 83.8
1.5	< 78.5	≥ 78.5	≥ 84.1	≥ 85.0
2.2	< 81.0	≥ 81.0	≥ 85.6	≥ 86.4
3	< 82.6	≥ 82.6	≥ 86.7	≥ 87.4
4	< 84.2	≥ 84.2	≥ 87.6	≥ 88.3
5.5	< 85.7	≥ 85.7	≥ 88.6	≥ 89.3
7.5	< 87.0	≥ 87.0	≥ 89.5	≥ 90.1
11	< 88.4	≥ 88.4	≥ 90.5	≥ 91.0
15	< 89.4	≥ 89.4	≥ 91.3	≥ 91.8
18.5	< 90.0	≥ 90.0	≥ 91.8	≥ 92.2
22	< 90.5	≥ 90.5	≥ 92.2	≥ 92.6
30	< 91.4	≥ 91.4	≥ 92.9	≥ 93.2
37	< 92.0	≥ 92.0	≥ 93.3	≥ 93.6
45	< 92.5	≥ 92.5	≥ 93.7	≥ 93.9
55	< 93.0	≥ 93.0	≥ 94.0	≥ 94.2
75	< 93.6	≥ 93.6	≥ 94.6	≥ 94.7
90	< 93.9	≥ 93.9	≥ 95.0	≥ 95.0

More information can be found in:

- “Definition of Standards for High Efficiency Electric Motors”, May 2004, OPET Network Slovenija
- the Euro-DEEM data base (see <http://re.jrc.ec.europa.eu/energyefficiency/eurodeem/>).

The International Electrotechnical Commission (IEC) has issued the standard IEC 60034-30 “Efficiency classes of single-speed three-phase cage induction motors (IE-code)”, which distinguishes four efficiency classes for electric motors from 0.75 kW to 375 kW. Table 19 gives a brief comparison between the two classes.

TABLE 19. COMPARISON BETWEEN IEC AND EU MOTOR CLASSES

IEC class	EU EFF class	Description
IE1	EFF2	Standard motor
IE2	EFF1	High Efficiency motor
IE3		Premium Efficiency motor
IE4		Super Premium motor

IE3 class efficiencies are set with 15 to 20% lower losses compared to the limits of IE2 (i.e. EFF1). IE4 is not yet defined, but envisaged for future editions of the IEC Standard. Efficiency data of IE1,2, and 3 can be found in the above mentioned IEC standard. In addition, the Motor MEPS Guide contains information on the efficiency classes IE1, 2, and 3 (Boteler, et al., Zürich 2009, see www.motorsystems.org for this guide).

Recently the European Commission has agreed on a new regulation that will set mandatory minimum energy efficiency standards for AC squirrel-case electric motors. This regulation will be based on IEC Standard 60034-30 (see above) and will contain the following measures:

- By 2011: a ban on sales of motors with efficiencies below IE2.
- By 2015: larger motors have to meet IE3 or IE2 if the motor is using a variable speed drive.
- By 2017: all motors have to meet IE3 or IE2 if using a variable speed drive.

This is viewed by the sector as quite an ambitious target. At present motor manufacturers have difficulty in reaching efficiencies higher than IE2 without significant redesign or using larger frame sizes.

BP 7 4. Motor Management Programme

With a motor management programme you can plan ahead the replacement of motors and drives on basis of a good knowledge and overview of your present motors and drives and their application and quality. This will be a helpful tool in your assessment of energy and costs savings and will also reduce downtime and minimise disruptions to your operations in case of motor failure.

The motor management programme comprises two parts:

- A Motor List; and
- Load-Time Profiles.

BP 7 4.1. Motor list

To set up this list, divide your plant into logical areas and list all motors, starting with the largest capacity downwards. You should define your own minimum thresholds regarding capacity and operating hours, whereby very small motors or motors with very low utilisation rates are excluded from the survey. The list should contain all relevant information about the motors, such as:

- The individual motor identification and name plate data
- The duty service and type of operation (e.g. boiler feed water pump, continuous or discontinuous operation)
- Speed of motor and driven equipment
- Type of variable speed control, if applicable
- Design load efficiency
- Operating voltage, amperage and power factor
- Average annual operating hours
- Average motor load and average motor efficiency
- Number and type of repairs

Depending upon the motor age, not all of this information might be directly available (such as, for example, data on efficiency and the power factor). In that case, you should try with the original equipment manufacturer to complete this information.

If the actual motor load is not yet measured, you can consider to performing in-situ measurement of voltage, ampere, power factor, and speed, using temporary measurements in order to establish the average motor load and efficiency.

The required measurements (in a three-phase power supply system) for each motor are:

- Phase-to-phase voltage between all three phases
- Ampere values for all three phases
- Power factor in all three phases
- Operating speed of motor and driven load

These measurements should be done by qualified electricians.

BP 7 4.2. Load-Time Profile

A second helpful tool is to develop Load-Time Profiles for the group of bigger motors to gather more detailed information on the annual running hours and at what loads and efficiencies. This requires a series of measurements, as described with the motor list, at various shifts, and different seasons to provide the necessary input. Load-Time Profiles can be helpful in your assessment of replacing inefficiently operating and/or oversized motors, and of variable speed options with drive systems in your plant.

BP 7 5. Main Areas of Potential Energy Efficiency Improvements

With the information described above as a basis, you can investigate the scope for improvements with motors and drive systems. There are four areas to look at:

- Replacement of standard motors with high efficient motors;
- Replacement of over-sized motors with smaller high efficient motors;
- Installing variable speed drives as a form of process control; and
- Good House Keeping measures with drive systems.

Each of these areas is addressed in more detail in the following sections.

BP 7 5.1. Replacement of Standard Motors with High Efficient Electric Motors

Replacement of a standard motor with a High Efficient (HE) motor can be considered in situations where:

- the motor need to be replaced because it is at the end of its life;
- a motor has failed and would need to be repaired; or
- the costs savings create a good business case for replacement.

Motor failures often have to do with failures in the stator winding insulation. Rewinding and reconditioning is common practice. An alternative could be to replace the standard motor with a HE motor and benefit from the improved efficiency.

As an average HE motors are approximately 2% points more efficient than new standard electric motors. Rewound motors however loose some efficiency (approximately 0.5% point with each repair). The investment in a HE motor with standard casing can be approximately 4% higher.

Replacing an aged motor with a HE motor instead of a standard motor can be beneficial as shown in the following example.

BP 7 5.2. The Business Case for EFF1 Motors

The annual savings can be calculated with the formula:

$$\text{Savings} = \text{hrs} \times \text{kW} \times \%FL \times (\text{€/kWh}) \times (100/\eta_{\text{standard}} - 100/\eta_{\text{HE}})$$

Where:

Savings	= the annual savings on electricity costs €/y
Hrs	= annual running time (hours)
kW	= motor rated power (kW)
%FL	= average fraction of rated output at which the motor is running (%)
€/kWh	= cost of electricity (€/kWh)
η_{standard}	= efficiency of existing motor (%)
η_{HE}	= efficiency of HE motor (%)

% FL information should be available from your motor list and Load-Time Profiles. If you do not know the efficiency of the existing motor, you can use the EFF3 upper level as an indication. If your motor has been repaired, you should take into account an additional loss of 0.5% point for each repair.

EXAMPLE

Suppose a 4-pole 22 kW motor is operating at 75% load for 6,000 hrs per year, with electricity costs of 0.08 €/kWh. The motor has been rewound once. What will the annual savings be when this motor is replaced by a HE motor? The standard efficiency is 90%, and the HE EFF1 efficiency is 92.6%. The annual savings are:

$$\text{Savings} = 6,000 \times 22 \times 0.75 \times 0.08 \times (100/90 - 100/92.6) = 247 \text{ €/year}$$

The investment for the HE motor may be in the order of €700. The simple payback period is 2.8 years.

BP 7 6. How to Improve Efficiency in Over-Sized Drive Systems

As a result of conservative engineering practices, drive systems are often substantially larger than they need to be. For example, centrifugal pumps are often over-sized because of added safety margins in the various design steps, starting with the process design up to the purchasing specification and the manufacturer's design to ensure it will meet the guarantees. In addition, process plant operating conditions may have changed, resulting in over-sized systems. Consequently, the driven equipment and the electric motor both operate far besides their optimal efficiency point. If this is the case in your plant, you can consider a number of improvements.

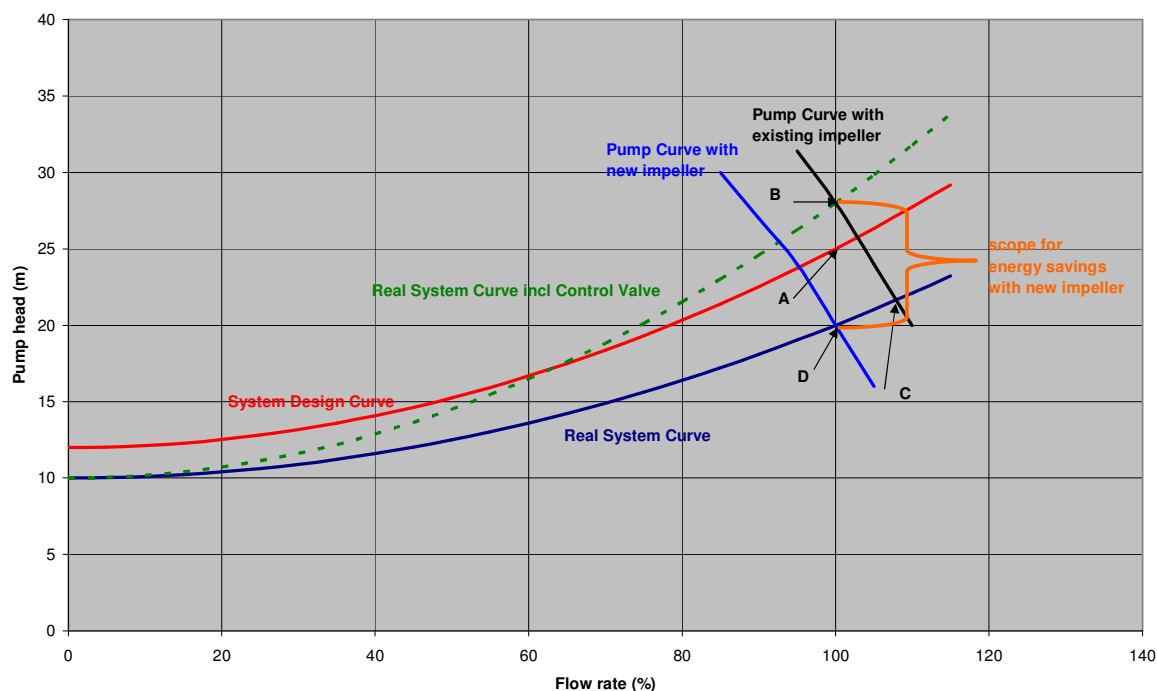
BP 7 6.1. Trim or Replace Impellers of Over-Sized Pumps

If a pump operates at conditions that are completely different to its design point, for example because the pressure in the system appears to be much lower than anticipated in the design and therefore the pump head is much lower than expected, this will cause a waste of energy, due to the flow control by throttling or by pass flow.

In this type of operation, you can consider to either trim or replace the pump impeller. Trimming means machining the impeller to reduce its diameter. This should always be done in consultation with the pump manufacturer to keep the impeller within the acceptable dimensions. If trimming is not possible, you can consider replacing the impeller with a smaller

diameter. Figure 26 illustrates the effect in the pump curve diagram.

FIGURE 26. EFFECT OF REPLACING THE PUMP IMPELLER



- Point A is the original design point on the design system curve.
- Point B is the real operating point of the pump.
- The throttling flow control controls (throttling the flow from point C to B) introduces extra losses in the system curve (see dotted line).
- Based on the real system curve – without the throttling losses - point D is the ideal point for the pump to operate at (with some margin of course for flow variations).

The reduction in required power with the new impeller can be calculated from the following formula:

$$P_2 = P_1 \times (H_2 \times Q_2) / (H_1 \times Q_1) \times (\eta_1 / \eta_2)$$

Where:

- Q = flow rate (m³/h)
- H = pump head (m of liquid column)
- η = pump hydraulic efficiency (%)
- 1 = with the original impeller
- 2 = after retrofit

If the flow rate is not changed ($Q_1 = Q_2$) the formula becomes:

$$P_2 = P_1 \times (H_2 / H_1) \times (\eta_1 / \eta_2)$$

EXAMPLE

Suppose a 110 kW pump, operating 6000 hours per year, can be equipped with a new impeller, that will reduce the required pump head from 28 m to 20 m to supply the same flow rate and improve the efficiency from 60% to 70%. The power with the new impeller will then be reduced to:

$$P_2 = 110 \times (20/28) \times (60/70) = 67 \text{ kW}$$

The annual energy savings are $(110 - 67) \times 6,000 = 258,000 \text{ kWh}$. If the kWh cost is 0.08 €/kWh, the annual cost savings are €20,640.

BP 7 6.2. Replace an Over-Sized and Under-Loaded Motor

For the same reasons as mentioned before motors rarely operate at their full load point. Motors operating below 50% of their rated power are no exceptions in the chemical industry. Motor efficiencies are relatively constant between 70% and 80% load and drop slightly from 80% to full load and from 70% to 50% load. Below 50% load efficiency begins to deteriorate significantly.

Using the inventory of your motor list you can check which motors operate at low loads and what their operating efficiencies are. Motors that operate at loads below 50% of their rated power for more than 2,000 hours per year are nominees for a retrofit. With this information, you can make an economic estimate of replacing the existing motor with a smaller HE motor, or you may schedule an overhaul of the motor. To accurately calculate the real savings you should consult a qualified electrician and the motor manufacturer to take into account all electrical aspects of such a retrofit. Nonetheless, the effects of rotating speed of the HE motor compared to the replaced standard motor are important. The actual operating speed of an induction motor is slightly lower (1-5%) than the synchronous speed. This difference in speed is called 'slip'. HE motors often operate with a reduced slip. This difference can be significant in calculating the energy savings of a retrofit, because the power consumption varies with the third power of the speed.

Operating efficiency and motor load must be derived from field measurements and motor nameplate information. To calculate motor part load you need to measure voltage, ampere, and power factor for all three phases. Motor load can then be calculated with the following formula:

$$P = \text{Voltage}_{\text{avg}} \times \text{Amp}_{\text{avg}} \times \text{PF}_{\text{avg}} \times \sqrt{3}$$

Where:

P	= motor load
Voltage _{avg}	= average voltage over 3 phases
Amp _{avg}	= average current over 3 phases
PF _{avg}	= average power factor over 3 phases

BP 7 7. Variable Speed Drive Technologies

The flow rate control of fluid flow equipment, such as pumps, fans, and compressors, driven by an electric induction motor, and running at a fixed speed, is often done by a throttling control valves in the discharge or the suction side of the equipment, or through a by-pass flow. In this case, part of the produced flow is directly fed back to the suction side, bypassing the end users.

In applications with variable flow demand and relatively little static pressure lift, variable speed drives in combination with AC induction electric motors can be an efficient and costs savings alternative for throttling or by-pass control, or on/off control, because the power requirement varies with the third power of the pump or compressor speed. However, in application where a more constant flow is required and/or static pressure lift is a significant portion of the total head, variable speed drive is not expected to be a cost effective way of flow control.

There is quite a variety of variable speed drives available on the market. The older types of speed control are:

- Mechanical and Hydraulic variable speed control;
- Eddy-current variable speed control;
- Multiple speed electric motors.

Today, the electronic Variable Speed Drive (often called Inverter, or VSD, or PWM) is the

more common technology for variable speed control, because of its good control characteristics, and due to its higher efficiency it is often more cost effective and can be used over a wide range of power output.

BP 7 7.1. Mechanical and Hydraulic Variable Speed Drives

Mechanical variable speed drives use an adjustable belt and pulley mechanism as a variable speed transmission between the motor and the motor-driven equipment to convert a fixed speed output into a variable speed output. Hydraulic variable speed drives use a type of hydraulic coupling between the motor and the driven equipment in which the torque is transmitted through the hydraulic oil. The output speed is adjusted by controlling more or less slip between the two hydraulic coupling parts (i.e. the constant speed part at the motor side and the variable speed part at the driven side). The hydraulic coupling is controlled via a hydraulic oil system, with pumps and coolers.

BP 7 7.2. Eddy Current Variable Speed Drives

Like the hydraulic coupling, the eddy current variable speed drive is also a type of slip controlled speed control. It consists of a drum connected to the constant speed shaft that surrounds a rotor connected to the variable speed shaft with a small air gap between drum and rotor. An adjustable magnetic field is created through which the torque is transmitted from the drum to the variable speed output shaft. The eddy-current drive efficiency depends upon the amount of slip (i.e. the difference between the full load speed and the operating speed). For example, at 80% speed the drive efficiency may be in the range of 76-80%. Compared to modern electronic VSDs, eddy-current drives are less efficient. Compared to electronic VSD they have relatively high mechanical losses.

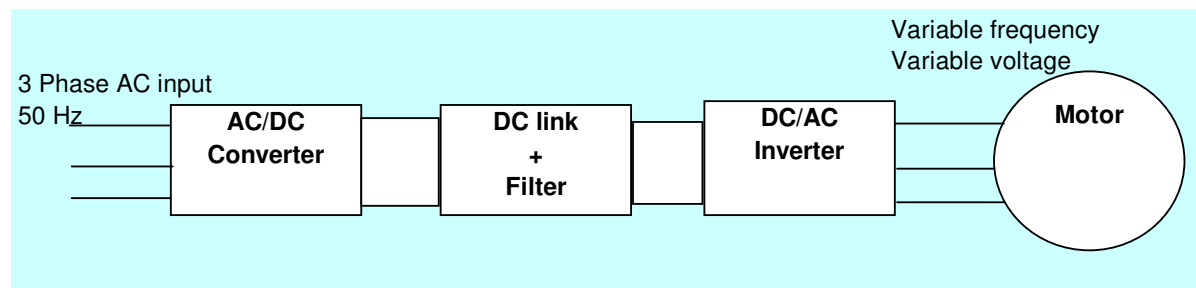
BP 7 7.3. Multiple Speed Motors

AC induction motors can be equipped with different winding configurations to operate the motor at two or four distinct speeds. Multiple motors are most commonly applied in situations where a stepwise flow control is required. Typical examples are in ventilation systems and with cooling tower fans.

BP 7 7.4. Power Electronic VSD (Inverters)

A normal AC electric motor operates at a fixed speed determined by the frequency of the supplied power (50 Hz). The induced rotating magnetic field in the motor, as the driving force, is directly linked with the frequency of the supplied power. Electronic VSD technology can convert the fixed frequency and fixed voltage alternating current into variable frequency, variable voltage alternating current by using special power electronic technology. As shown in Figure 27, this VSD consists of an AC/DC Converter that converts alternating current into direct current, a DC filter to create the correct DC current and finally a DC/AC Inverter that converts the DC voltage to variable AC voltage at variable frequency. The AC output is then supplied to the motor.

FIGURE 27. GENERAL CONFIGURATION OF AN ELECTRONIC VSD



There are a few aspects to consider when investigating VSD applications:

- It could be that your present AC electric motor is not suitable for use with a power electronic VSD, because of the nature of the synthesised voltage waveform. So most probably, you have to include the change to a HE motor.
- VSDs could create some higher harmonics in the power supply system that can affect other users. In that case, harmonic filters will need to be installed as well.
- Because of the power electronics in the system, VSDs need to be placed in a clean and dry environment.

The conversion steps in a VSD from AC to DC to adapted AC require some energy. VSDs typically are 92-95% efficient. These losses have to be taken into account in the overall economic assessment.

VSDs have the possibility of 'soft' starting of the motor, avoiding high starting currents in the motor and reducing voltage dips in the power distribution system.

A recent development is to integrate the VSD with the motor. This has a number of advantages, such as lower installed costs and elimination of electromagnetic interference problems, etc. An example for an integrated VCD is shown in Figure 28.

FIGURE 28. INTEGRATED VSD



Source: Siemens

Presently their application is in the lower power range (up to approximately 15 kW). There are various forms of power electronic VSD and you should consult a qualified supplier to select the most suited type.

BP 7 8. Opportunities and Benefits of Variable Speed Drives

BP 7 8.1. Variable and Constant Torque Applications

In assessing the applications for variable speed drives, it is important that you evaluate the type of torque that is required for the specific driven equipment. With fluid flow equipment such as, pumps, air fans, and compressors the discharge pressure at the outlet of the pump, fan, or compressor consists of a static part (static lift) and a dynamic part. The static part is determined by the process pressure at the supply point, for example the pressure in a process vessel, or the pressure at the end users in a compressed air system. The dynamic part is the fluid flow friction that has built up in the system from supply point to end user point, and varies to the second power of the fluid velocity.

Applications where the static lift is a relatively large portion of the total supply pressure

require an almost constant torque over the whole flow control range (variable flow at constant pressure). Examples are air compressors, mixers and conveyors. Applications with a relatively large dynamic pressure part require a more variable torque over the whole flow control range (variable flow and variable pressure). Examples are air fans and pumping systems.

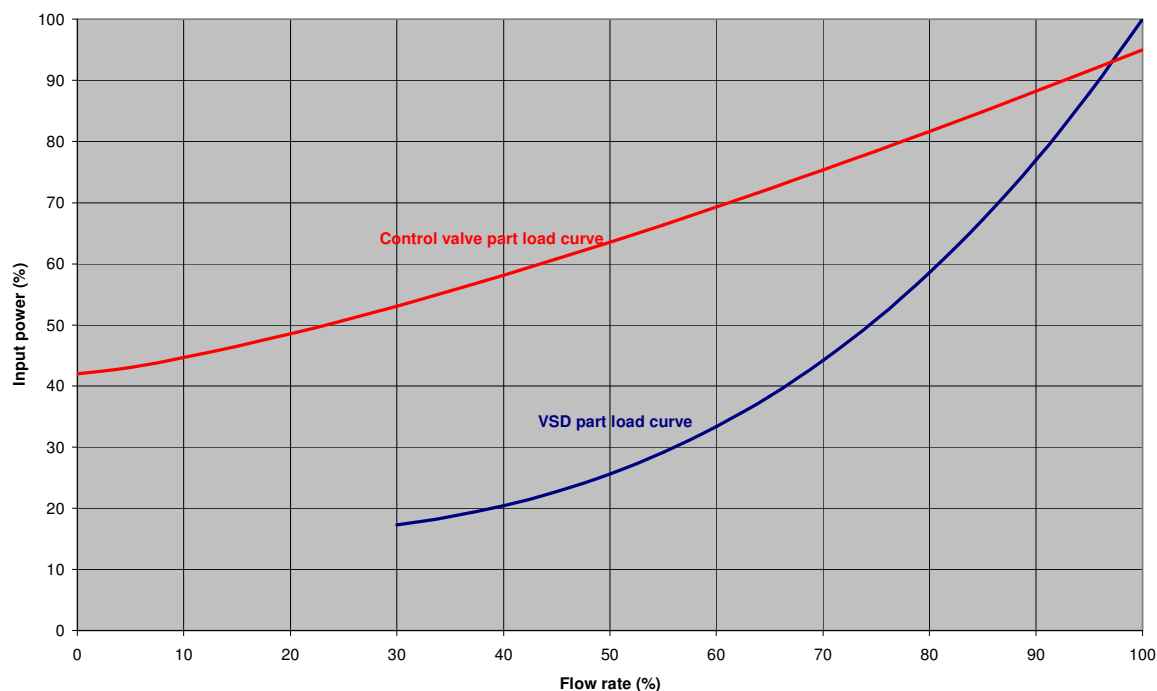
The potential for energy savings with variable speed drives depends upon the type of torque that is required for the application. Those with a more variable torque will create relatively bigger savings than with constant torque, because with constant torque the energy input decreases almost linear with lower speed, as with variable torque this will reduce to the second power of speed. Therefore, the most interesting applications to consider variable speed drive are in order of preference:

- Pumps
- Air fans
- Process compressors
- Air compressors
- Conveyors
- Others

BP 7 8.2. Pumps

The most common flow control in pump systems is with a flow control valve in the discharge of the pump. This often results in a waste of energy as the pump is not running at its optimum point. Using a variable speed drive instead of a throttling control valve can result in substantial energy efficiency improvement and therefore cost savings. This is illustrated in Figure 29, where the power required with a fixed speed and control valve is compared to a variable speed drive.

FIGURE 29. COMPARISON OF POWER REDUCTION IN PUMPS WITH VSD AND THROTTLE CONTROL



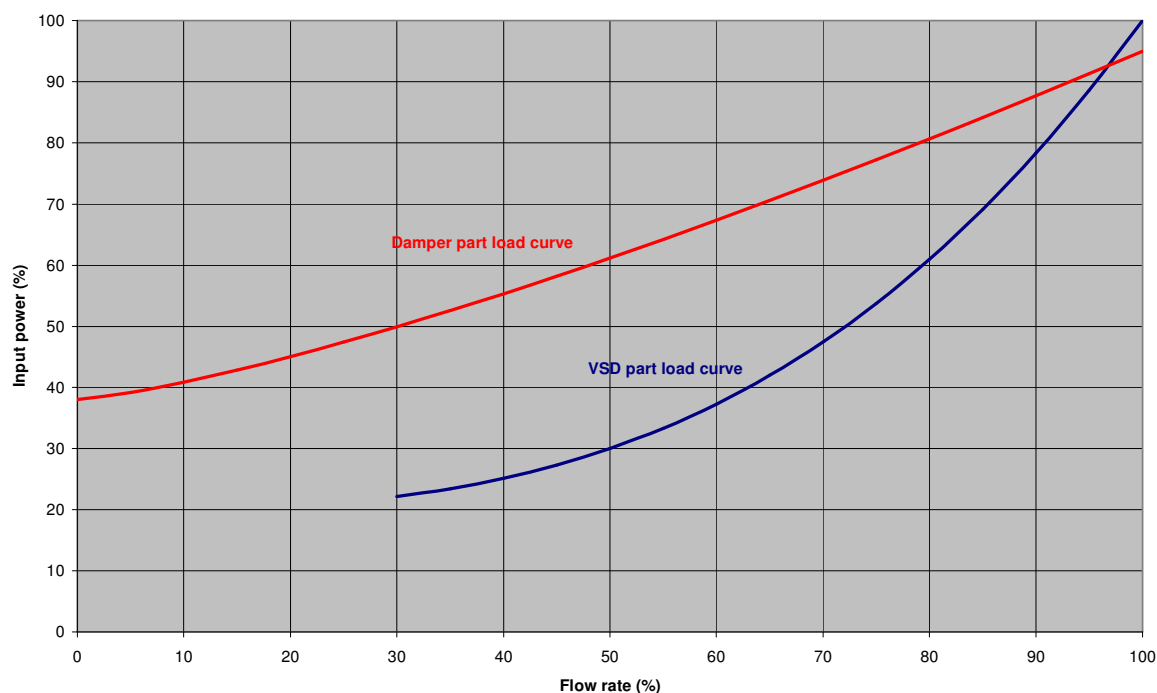
The horizontal axis gives the flow rate as a percentage of the design flow. The vertical axis is the input power as a percentage scale of the power required by the VSD. With the throttle control valve the power required reduces at a nearly linear rate with the decreasing flow rate (the efficiency of the pump will also be reduced). With a variable speed drive the power required decreases more or less with the second power of the decreasing flow (with the third power of the speed). In this example, the VSD can be used down to a 30% flow rate. Below

that point, the speed of the pump is not sufficient to provide enough discharge pressure to match the system pressure (mainly the static head). Because of the inherent losses in the VSD, it is less efficient than the control valve at flow rates between 100 % and 95 %.

BP 7 8.3. Air fans

Similar to using a control valve with a pump, dampers are often used to control the flow of the fan. Reducing the speed is a much more energy efficient form of control. This is illustrated in Figure 30.

FIGURE 30. COMPARISON OF LOAD REDUCTION IN FANS WITH VSD AND DAMPER CONTROL



Example of energy saving with VSD

Suppose an air fan operates 6,000 hours per year at an average annual flow rate of 60% of its design capacity. The design power is 160 kW.

With damper control the annual power input is:

$$68\% \times 160 \text{ kW} \times 6,000 \text{ hrs} = 652,800 \text{ kWh/y}$$

With VSD the annual power input is:

$$38\% \times 160 \text{ kW} \times 6,000 \text{ hrs} = 364,800 \text{ kWh}$$

The annual savings with VSD are 288,000 kWh. At a kWh cost of 0.08 €/kWh the costs savings are €23,040 per year.

BP 7 8.4. (Air) Compressors

The potential for variable speed drives with compressors depends very much on the type of compressor, the type of torque (more constant or more variable) that is required, and what form of capacity control is presently being used. For example, centrifugal compressors or axial compressors operating in a system with a high static head are less likely to be candidates for variable speed drives. However, with constant torque compressors, such as piston compressors and screw compressors, improvements could well be achieved with a variable speed drive, as it can replace a less efficient capacity control. It is important to take into account that often positive displacement compressor need to operate above a minimum acceptable speed. Therefore, you should always consult your compressor supplier in considering such a retrofit.

BP 7 9. List of measures for motor and drivers

A list of good housekeeping measures can be found below.

Good Housekeeping Measures	
1	Switch off motors when they are not in use, prevent pumps operating for longer time over their minimum by-pass control
2	Apply regular maintenance on all components of your drive systems
3	Check coupling alignment, lubrication, and pump seal maintenance
4	Replace excessively leaking seals and packing
5	Regularly check electric motor condition, amongst others the condition of motor winding insulation
6	Conduct a survey of belt-driven equipment. Gather data on application and operating hours. Determine the cost effectiveness of replacing V-belts with cogged belts or synchronous belts
7	Conduct a survey about the quality of your in-plant power distribution
8	Check the distribution system for unevenly distributed single-phase loads
9	Eliminate voltage unbalances, because they can seriously degrade the performance and shorten the lifetime of three-phase motors
10	Eliminate excessive voltage drops in your in-plant distribution system
11	Check the power factor in your in-plant distribution system and evaluate measures to improve the power factor

Below you have an additional check list for your motors.

Motors

Energy Saving Opportunity	Action to Check
1. Try to ensure that motor capacity is not more than 25% in excess of full load.	-
2. Install motor controllers (voltage, power factor and fixed speed controllers).	-
3. Build in "soft-start" facilities.	-
4. Install variable speed drives	-
5. Install high efficiency motors	-

Source: www.bess-project.info

BP 7 10. Further Information

Best Practice How to Improve Energy Efficiency With Your Motors And Drives

As part of a large group of measures which altogether led to energy savings of more than 40% on the base load demand, a chemical SME replaced the old low-efficiency electrical motors, with high efficiency ones. This measure saved 10% of energy used for motors and had an average payback period of 2 years.

BP 7 10.1. Additional reading

- Carbon Trust, www.carbontrust.co.uk

Examples

- Variable speed drives, Introducing energy savings opportunities for business, CTG006
- Compressed air CTV017
- Motors and drives CTV016

2. Improving Motor and Drive System Performance: a Sourcebook for Industry, US DOE, Office of EERE,
<http://www1.eere.energy.gov/industry/bestpractices/motors.html>
3. Variable Speed Pumping, a Guide to Successful Applications, US DOE, Office of EERE,
www.pumps.org, www.europump.org
4. Motor efficiency classes www.motorsystems.org

Best Practice 8 How to Improve Energy Efficiency in Your Production Processes

BP 8 1. Introduction

Chemical plants work with energy intensive process units. Therefore, investigating the potential for energy performance improvement makes perfect business sense. Potential for energy savings can be considered within the process unit operations themselves, and secondly in options for heat recovery in the process areas. This Best Practice describes a number of possible improvements in process unit operations, such as distillation, evaporation and drying. For practicality, this is provided in a generic way, as there is so much variation across chemical processes. Whether or not they can be applied in your specific situation needs to be evaluated with the input of technical experts in this field. Furthermore, potential applications of membrane technologies and a number of high temperature heat recovery technologies are described as these have great potential for energy savings. The last part describes the headlines of a structural heat recovery analysis method (pinch analysis) that you can apply to find scope for heat recovery in your plant.

BP 8 2. Process Areas with Potential for Energy Efficiency Improvement

BP 8 2.1. Distillation

Distillation is applied to separate mixtures, consisting of components with different boiling points, by heating the mixture to the required temperature in its boiling temperature range, for example to purify a product. A typical distillation process consists of a combination of a reactor where the incoming mixture is heated and a distillation column where the mixture is separated and a re-boiler to maintain the boiling conditions in the column. Normally, these basic components are well integrated into the whole separation process, with several heat exchangers in the product streams to exchange heat.

Scope for savings can be found in:

- Further heat integration (see for a systematic analysis section 5 of this Best Practice);
- Using more efficient distillation trays or column packing;
- In some cases, there are less energy intensive alternatives to distillation that you could consider. These include evaporation using membrane technology for separation. With evaporation it can also be possible to directly separate azeotrope mixtures. Azeotrope mixtures have one boiling point (lower than of either pure component). So with normal distillation further purity of the product cannot be achieved, and special, more energy intensive azeotropic distillation is required.
- Optimisation/ adaptation of the reflux ratio / back flow ratio of the electricity per unit of product: Many distillation columns are run with a constant backflow electricity volume. If the electricity input into the column is changed, the back flow electricity volume is often not adapted. This is equal to electricity destruction and should therefore be avoided.

It should be noted that the first three types of changes would be significant modifications of the process. They could, however, be considered in a situation of redesign or expansions.

BP 8 2.2. Evaporation

Evaporation is applied to remove water and further concentrate a liquid. The main energy input is to increase the temperature of the feed to the water boiling point and to convert the water into steam that is removed from the evaporator vessel. Scope for energy savings can be found in:

- Reducing the amount of water that needs to be evaporated. One way of reducing the amount of water is to consider a pre separation step using membrane technology.
- You could also consider recovering the heat of the evaporated water in a condenser for

low temperature heating purpose.

- Another alternative is to apply a mechanical vapour re-compression as a heat pump to compress the steam and use it as a heating medium in the evaporator.
- Another possibility is to use more efficient multi stage evaporators.

BP 8 2.3. Drying

Drying is applied to remove water from a solid product by the addition of heat.

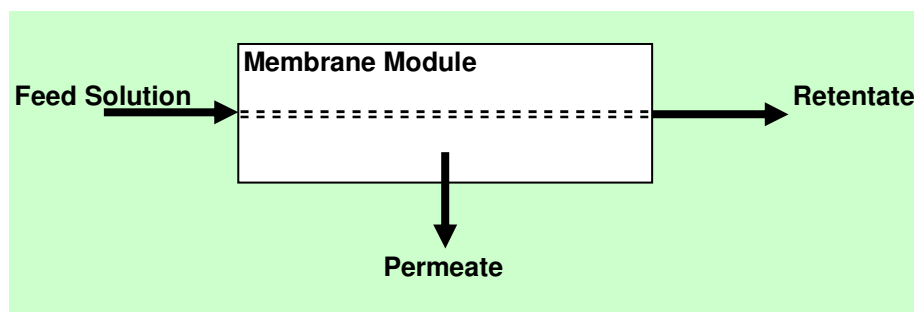
Options for energy efficiency improvement are:

- Reduce the water content of the solid before it is dried. This would require process changes, such as installation of special type slurry pumps suitable to transport streams with a higher concentration of solids.
- Ensure that the dryer operation is well controlled and maintained, and hot surfaces have adequate insulation.
- Consider opportunities to recover the waste heat from the hot air leaving the dryer.

BP 8 3. Energy Savings Options Using Membrane Technology

Membrane technology has rapidly developed over the last decade as a mature separation technology for a variety of applications. The big advantage of membrane technology is its relatively low energy consumption compared to other separation technologies, such as distillation and evaporation. Figure 31 gives the basic principle.

FIGURE 31. MEMBRANE SEPARATION TECHNOLOGY



Usually the feed solution is flowing through the membrane. The permeate stream passes through the membrane wall. The retentate are the components that do not pass the membrane wall. Membrane technology can be used in a number of separation technologies:

- Pressure driven membrane filtration, such as: micro-, ultra-, nano-filtration, and reverse-osmosis filtration to purify liquids, for example in water treatment.
- Electro-membrane technology, where charged membranes are used to separate charged particles (this is a combined electrolysis technology and membrane technology).
- Gas separation membranes, for separating gases such as CO₂ and hydrogen.
- Pervaporation membranes, used, for example, to break azeotropic mixtures. Recently, ceramic-based pervaporation membranes have been developed, which are suitable for process temperatures above 100°C (instead of the more common polymer membranes, which can be applied up to 100°C).
- Pertraction with liquid membranes. A liquid membranes consists of a porous membrane support structure with a polymeric liquid coating the pores. The polymer is selected for its affinity to the components that need to be separated from the feeding flow. With the polymeric liquid coating the membranes realise transport of solutes between two liquid phases (feeding and stripping solutions), separated by the membrane. Typical use is with processing wastewater streams. For example, wastewater flows contaminated with aromatic or chlorinated hydrocarbon substances can be cleaned by absorption into an organic extraction agent. The membrane is the interface between the wastewater and the extractant. The fact that the extractant is kept separate from the wastewater is a great advantage compared to conventional

extraction processes, which require an additional separation step.

BP 8 4. Heat Recovery Equipment

Various heat recovery techniques are available to capture and reuse part of the waste heat that is available from chemicals processes.

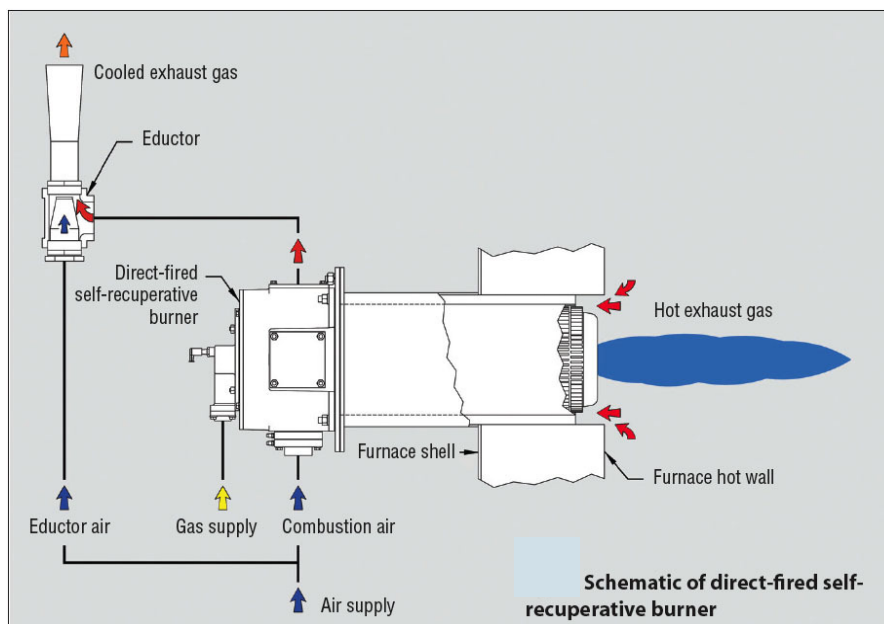
High temperature heat recovery equipment is available:

- Recuperation using heat exchangers to recover waste heat. In case of high temperature, ceramic recuperators are available on the market.
- Regenerators recovering heat from flue gases to pre heat combustion air of furnaces and boilers.

Heat exchangers are available in a wide variety of types, covering the whole range of waste heat temperatures.

To determine what ultimate types of heat recovery devices will be suitable for your particular application requires thorough investigation and specialist advice from equipment suppliers. One of the most widely used heat recovery applications is to use hot flue gases for pre-heating combustion air in furnaces. Process furnaces often operate with rather high process stream temperatures and therefore have a rather low efficiency. Recuperating part of the heat in the exhaust gases to pre-heat the combustion air can substantially increase the fuel efficiency. An interesting development is the self-recuperative burner, which has the recuperator fully integrated in the burner construction. A scheme of such a burner is given in Figure 32.

FIGURE 32. SELF-RECUPERATIVE BURNER



Source: Hauck Manufacturing, USA

Installing high temperature heat recovery equipment requires careful design, engineering and construction and must be executed by qualified people. You should pay attention to:

- The consequences of the slightly higher pressure drop over the combustion air – fire box – flue gas path to check whether these changes are acceptable for the furnace and can be handled by the air fans, or if an induced draft fan is required.
- The impact on the furnace controls.

- What burner modifications are required to operate with higher combustion air temperatures.
- The longer term maintenance of the equipment to avoid fouling and corrosion, which could completely eliminate the anticipated energy savings.

BP 8 5. Assessing Your Scope for Heat Recovery through Pinch Analysis

Pinch analysis is a method to define the minimum required energy input that your process would require if an optimal heat exchange would be realised. For obvious reason this optimum cannot really be achieved but the analysis can give valuable information as to how you can further optimise the heat recovery in your plant. The method was introduced by the University of Manchester (UK) and has since then been successfully used in many chemical companies. There is a variety of literature available on the internet, explaining the method in detail.

Here a brief explanation of the essentials is given. The method consists of two basic steps:

- First, the analysis of the minimum required heat input into the process and cooling load from the process, by comparing the total of the cold streams (that need to be heated) and the total of the hot streams (that need to be cooled), and how they can be interlinked to achieve an optimal heat exchange.
- Second, a (re)design of the heat exchanger network to realise the minimum heat input target.

BP 8 5.1. Analysis of the Minimum Heat Input and Cooling Load Requirements

The process flows are represented as a set of energy flows as a function of heat load (kW) against temperature (°C). All process streams in the plant that need to be cooled (the hot streams) are combined in the hot composite curve. A composite curve is the relationship between the total duty in kW and the temperature of the process streams. All the cold streams in the plant that need to be heated are combined in the cold composite curve.

In the following example it is illustrated how the composite curves are being developed. In the example, there are two hot streams and two cold streams with supply and target temperatures as specified in Table 20.

TABLE 20. PROCESS STREAMS

Stream	Type	Supply Temperature (°C)	Target Temperature (°C)	Duty Q (kW)	mCp (kW/°C)
1	hot	200	100	2000	20
2	hot	150	60	3600	40
Total	hot			5600	
3	cold	80	120	3200	80
4	cold	50	220	2550	15
Total	cold			5750	

The heat transfer duty can be expressed with the following formula:

$$Q = m \times Cp \times \Delta T \text{ (kW)} \rightarrow mCp = Q / \Delta T \text{ (kW/°C)}$$

Where:

Q = heat duty (kW)

m = mass flow (kg/sec)

Cp = specific heat content (kJ/kg/°C)

mCp = heat capacity flow rate (kW/°C)

To construct the composite curves you need to know the mass flow, the pertaining C_p value and the supply and target temperatures of the process streams. The first step is to put the cold streams and hot streams in a temperature/duty diagram as shown in Figure 33.

FIGURE 33. HOT AND COLD COMPOSITE CURVES

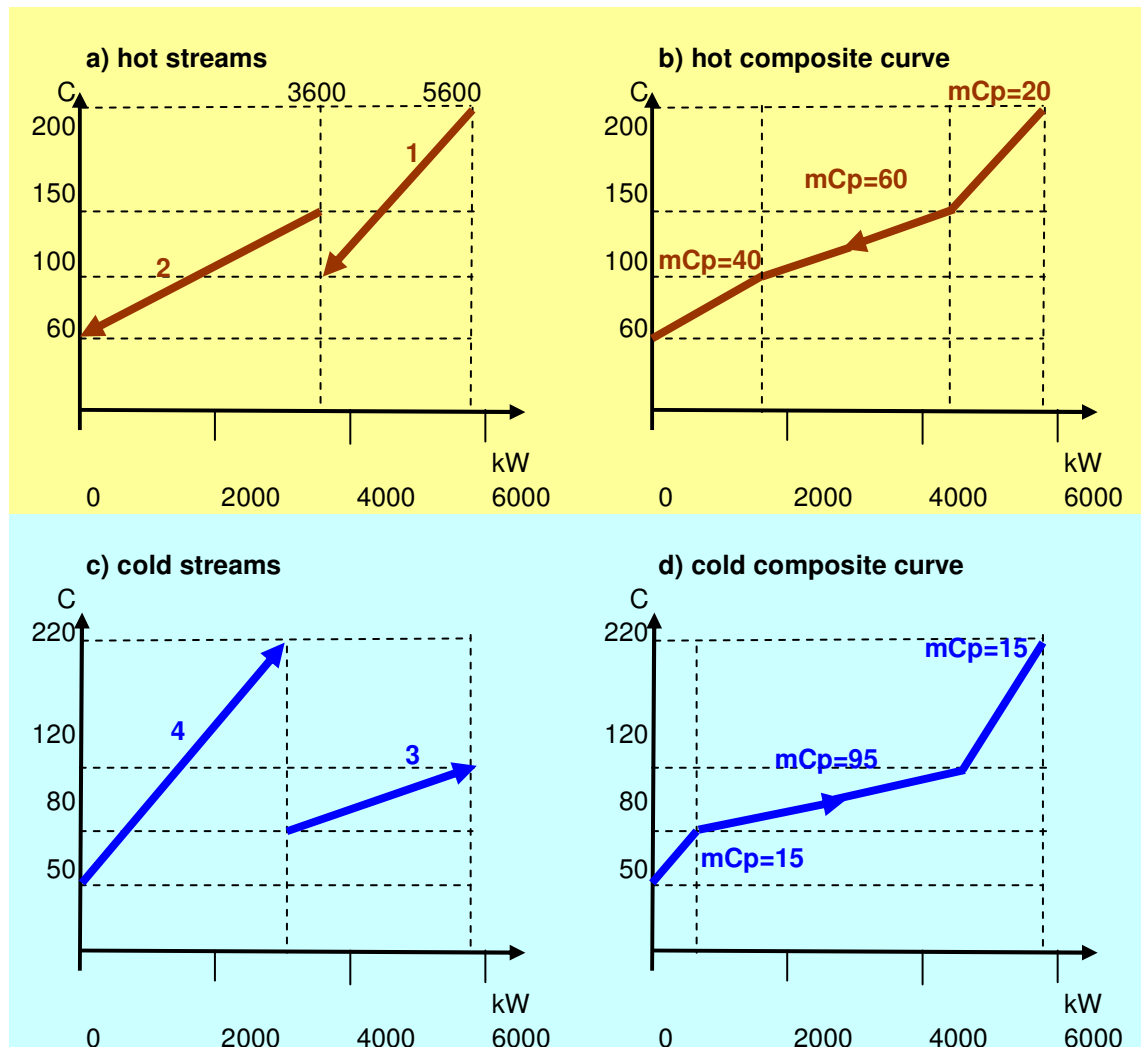


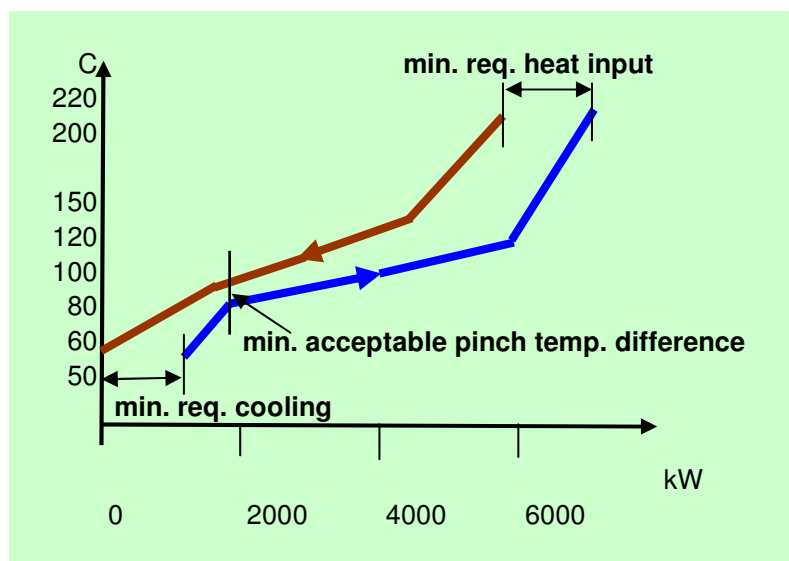
Diagram a) shows the individual hot streams in the temperature/duty diagram. From this diagram the hot composite curve can be made, by adding the mC_p values over each temperature interval, as shown in diagram b). The temperature intervals for the hot streams are:

- 200-150°C with $mC_p = 20$
- 150-100°C with $mC_p = 60$
- 100-60°C with $mC_p = 40$

The same can be done for the cold streams. Here the temperature intervals are:

- 50-80°C with $mC_p = 15$
- 80-120°C with $mC_p = 98$
- 120-220°C with $mC_p = 15$

To determine the minimum energy target for the process, the cold composite curve is now progressively moved towards the hot composite curve till the minimum acceptable temperature difference for heat transfer, called the pinch point. This is shown in Figure 34.

FIGURE 34. DETERMINING ENERGY TARGETS


The horizontal duty axis now indicates only duty differences between cooling and heating and no absolute cooling or heating duty.

From this composed curve, you can now determine the minimum required heat input into the process and the minimum required cooling duty with a maximum (theoretical) heat recovery. With such a diagram as in Figure 34 you can do a pinch analyse to check the present heat recovery in the process. There are a few rules that are applicable:

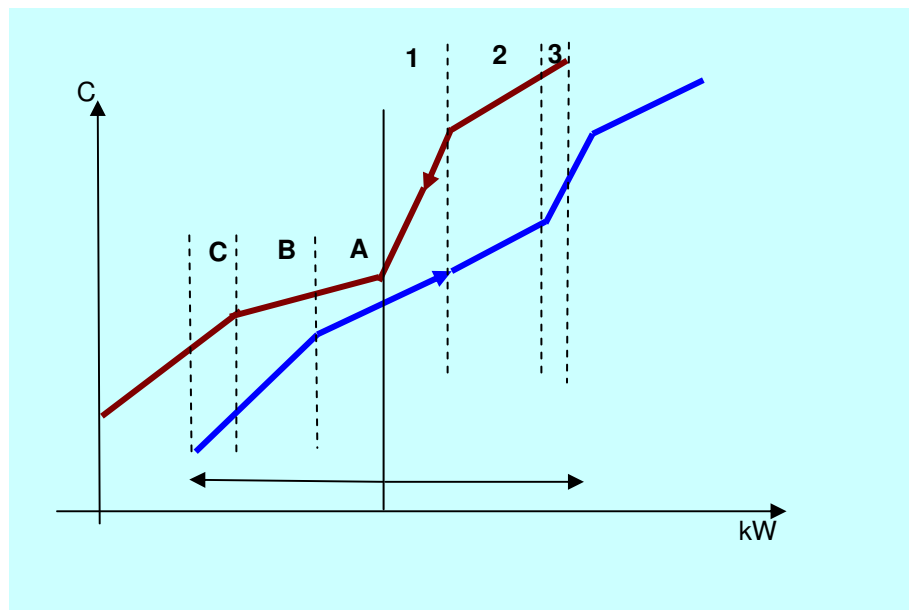
- In the region above the pinch temperature there is a shortage of heat for the cold streams, so all heat available in the hot streams in that temperature region should be used for the cold streams in this region and not in the region below the pinch.
- In the region above the pinch there should also be no external cooling of hot streams, as, thermodynamically, all waste heat can be utilised to heat the cold streams.
- In the region below the pinch there is surplus of heat available in the hot streams to heat the cold streams in that temperature region, so here there should not be external heat added to the cold streams, nor from the hot streams above the pinch.

In summary, ideally the optimal heat recovery should adhere to the following rules:

- No external heating below the pinch
- No external cooling above the pinch
- No heat transfer across the pinch

The pinch point depends on your selection of the minimum temperature difference that is applicable for your plant. This is an economic selection to balance energy savings versus investment.

The second part of the pinch analysis is to develop a heat exchanger network to realise the minimum target or the best match that you can make. To optimise the heat exchanger network you can divide the composite curve into segments, starting from the pinch point, of constant slope duty intervals, as indicated in Figure 35.

FIGURE 35. DUTY INTERVALS FOR OPTIMAL HEAT EXCHANGER NETWORK DESIGN


These intervals are A, B, and C for the area below the pinch, and 1, 2, and 3 for the area above the pinch. Optimal heat exchange should take place within these intervals. For each interval, the hot streams and cold streams are known, as well as the temperature range. This enables you to make an optimal heat exchanger network, or the best practical match.

BP 8 6. List of recommended measures

Please find below a list of recommended measures that you can use as a starting point in your Energy Efficiency Self Audit.

Heat Utilization in the process

Energy Saving Opportunity	Action to Check
1. Plant insulation	-
2. Local burner efficiency	-
3. Maximise heat transfer rate	-
4. Improve controls (e.g. thermostats)	-
5. Consider alternative energy source	-
6. Ensure plant at high load factor	-
7. Eliminate uneconomic hot standby periods	-
8. Recycle waste heat to process	-
9. Recover heat, for use elsewhere	-
10. Train all staff to operate manual controls and to watch for energy saving opportunities.	-

Source: www.bess-project.info

BP 8 7. Further information

Best Practice How to Improve Energy Efficiency in Your Production Processes

The CARE+ audits have analysed a chemical SME that is equipped with dryers with a two stage burner, which leads to a rather high gas consumption. A replacement of the burner with a boiler type burner which is capable to operate with most of known fuels would lead to a decrease of gas consumption of 158 000 m³ and lower power demand which could lead to savings of approximately €56000. In addition it gives the company the opportunity to switch fuel, if necessary. The cost of investment for the new boiler is €81250 excluding storage tanks. In addition it is recommendable to modernize the existing ceramic combustion chamber at an approximate cost of €37500. The total cost of modernization should amount to €120000. Taking into account the expected savings, this energy saving investment would have a pay back period of around 2 years.

BP 8 7.1. Additional reading

1. How to install industrial heat recovery equipment, CTL037 Carbon Trust
www.carbontrust.co.uk
2. Pinch Analysis: For the Efficient Use of energy, Water & Hydrogen, ISBN: 0-662-34964-4; <http://canmetenergy-canmetenergie.nrcan-rncan.gc.ca>
3. Sector Overview, Chemicals sector, Introducing energy saving opportunities for business, Carbon Trust CTV012; www.carbontrust.co.uk

ANNEX 1: References and Further Reading

In the development of these Best Practices, use has been made of valuable information that has been published by many organisations that are active in this field. The following list gives the main sources that have been used.

Best Practices Energy Management, Energy Accounting, Energy Information System

Practical energy management, Carbon Trust publication CTV023, www.carbontrust.co.uk

Step by step to energy strategy, Carbon Trust publication CTV022; www.carbontrust.co.uk

Guideline for energy management, EPA EnergyStar publication, www.energystar.gov/index

Step by step guidance for the implementation of energy management, handbook Bess Project, www.bess-project.info

Energy Efficiency Planning and Management Guide, Canadian Industry Program for Energy Conservation (CIPEC), <http://oee.nrcan.gc.ca>

Energy Information Systems, Achieving Improved Energy Efficiency, Handbook published by the Office of Energy Efficiency of Natural resources Canada, <http://oee.nrcan.gc.ca>

EMAS Energy Efficiency Toolkit for Small and Medium sized Enterprises, The European Eco-Management Audit Scheme, www.europa.eu.int/comm/environment/emas

Several publications from SenterNovem on energy management, www.senternovem.nl/mja

US DOE, Energy Efficiency and Renewable Energy, several publications on energy Management, www.eere.energy.gov

Monitoring and targeting; Techniques to help organisations control and manage their energy use, Carbon Trust publication CTG008; www.carbontrust.co.uk

Focus on Energy, A practical introduction to reducing energy bills, Actionenergy publication, www.actionenergy.org.uk

Several publications from Commissie Auditconvenant energie efficiency; www.auditconvenant.be

Best Practice How to improve your Steam Generation Performance

Het Ketelhuis, Produktie en gebruik van stoom in de praktijk, N. Duinkerken, 2006, ISBN 10: 90-9021090-3

Stooktechnologie, Senternovem/VNCI publication

Steam and high temperature hot water, introducing energy savings opportunities for business, Carbon Trust publication CTV018 Technology overview; www.carbontrust.co.uk

Improving Steam System Performance, A Sourcebook for Industry, US DOE, Office of Energy Efficiency and Renewable Energy, www.eere.energy.gov

Steam System Opportunity Assessment for the Pulp and Paper, Chemical Manufacturing, and Petroleum Refining Industries, US DOE, Office of EERE

Several other US DOE publications on energy savings technologies with steam www.eere.energy.gov

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Brochure Perslucht en energiebesparing, Nederlandse Rubber- en Kunststoffindustrie, 2005, SenterNovem publication

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Sustainable Manufacturing – Fact Sheet – HVAC TIPS; www.sustainable-energy.vic.gov.au.

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