Curriculum of the European Energy Management Course

*** Preparation material ***

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Biogas Characteristics
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- [www.energiemanager.ihk.de](http://www.energiemanager.ihk.de)
- [www.european-energymanager.net](http://www.european-energymanager.net)
- [www.nuernberg.ihk.de](http://www.nuernberg.ihk.de)
- [www.projects-online.de](http://www.projects-online.de)
- [www.energyinst.org.uk](http://www.energyinst.org.uk)
- [www.uba.de](http://www.uba.de)
- Energy utilisation – the Austrian Energy Agency (E.V.A.)
- Federal Environmental Agency of Germany
1. General EU law

The European Union is a legal community that consists of a system of legal standards that, according to their rules of creation, can be classified into various types of standard levels.

The most important position within EU law is taken by primary law where a decision for its application is by means of a declaration of intent by a member state. Besides the treaties, numerous protocols as well as alterations to the treaties decided by member states are also applicable. An example of one such treaty alteration is the EU entry treaty that also needs to be taken into account as part of EU primary law. Included in EU primary law are the rules for the creation of further legal standards, for EU secondary law and EU derived laws respectively. Depending upon the sphere of influence and the effect, one differentiates between regulations which are directed at all EU member states and community members and which are immediately mandatory in all areas; guidelines that are directed at all or certain membership states and only are binding with respect to predetermined goals and which are regularly incorporated into the internal laws of member states; decisions which are directed at certain member states or certain persons and which are binding on both of them; and recommendations or statements aimed at all or certain member states but which are not legally binding.

On the basis of EU primary law, there are already some commitments for member states and citizens of the membership states that relate to the domestic energy market. This applies particularly to article 12 of the EU treaty that excludes discrimination on the basis of citizenship. This means that it is basically not possible under state law to grant a certain right only to their own citizens or businesses that are domiciled in that particular member state. Article 14 also defines the single European market as an area without internal borders where the free movement of goods, people, services and capital must be guaranteed in accordance with the provisions of the treaty. Alongside the principle of freedom from discrimination and the principle of the free exchange of goods, the general provisions relating to competition laws and public monopolistic companies, as well as the provisions relating to assistance law, are also of particular importance.
Overall it should be noted that the situation prevailing before liberation of the electricity and gas markets in the European Union contradicted most, if not all, of these provisions. In this regard there were many special rights that were limiting the internal European market and which were reserved for companies or citizens of a particular member state. Public owners were used to demanding non-market interest rates for capital employed etc.

However, it should be noted that the EU treaty does not recognise a fundamental ban on monopolies. It merely forbids the misuse of a monopoly position. The particular cases covered by regulations are those cases where the monopoly status of a company has been granted as the result of national legal order or as the result of the granting of special or exclusive rights. The member states are required to ensure, with respect to public and private businesses to which special or exclusive rights have been granted, that none of these measures that contradict the treaty are retained. The granting of a legal monopoly is fundamentally in accordance with the treaty but abuse of this position is not permitted. A further limitation to the general freedom of the movement of goods applies to essential service companies. Companies in charge of serving general commercial interest only have to fulfil the regulations of the EU treaty, particularly the rules relating to competition, to the extent that their fulfilment does not create a hindrance to them being able to effectively deliver services of general commercial interest. In this regard, an actual or legal impediment to the fulfilment of their duties is enough for them to be absolved from the commitments of the rules of competition.

As a consequence, that is why there has been intense discussion about the manner and extent of public interest in the duties and responsibilities of the electrical utility companies. At this point it needs to be noted that the network operator in particular has these duties and, as a monopoly company, is not subject to competition, whereas essential services in the areas of electricity production and distribution appear to be exceptions.
2. **Guidelines for the internal EU electricity market**

On the June 20, 1996 at a special meeting of the EU Council of Ministers for Energy in Luxembourg, a unanimous political agreement was achieved regarding a collective view in favour of a guideline from the European Parliament and the Council concerning common rules for the internal EU electricity market. This marked the end of more than 5 years of negotiations. For the first time in its 100-year history, this branch of the economy was, at least in part, brought under the jurisdiction of the rules applying to the free market. The background to the negotiations associated with this guideline was primarily the aim to develop a free competitive market for the production and marketing of electricity but, in contrast, to permit regional monopoly companies in the areas of electricity transmission. Because the electricity networks are portrayed as being so-called “essential facilities”, each market participant, offering party, or consumer, must use these facilities. This regulation is of special importance because electricity distribution networks are so called “essential facilities” and so every market participant must use these facilities. This approach to the regulation of networks is of particular importance.

The guidelines agreed to in 1996 in fact on one hand regulate the fundamental provisions with regard to new producers entering the market but, on the other hand, the focus of these provisions is the regulation of network operators. The rights and responsibilities of the transmission and distribution network operators are specified. For this reason no non-approved cash flows can occur between competitive areas such as production, distribution, and the monopoly network area and so divestiture and transparency in the accounting area needs to be brought in. In this way the intention is to ensure that older established integrated electricity supply companies don’t use money earned from the distribution network to support their own competitive positions. On the other hand, the network operator is required to only demand tariffs that truly correspond to the costs incurred by the network operator and, in particular, not the costs of marketing.
Originally the guidelines envisaged a gradual opening up of the market to a little more than 30% by the year 2003. The experience of the EU members was that some member states with a high level of market openness tried to restrict the free play of market forces because of inefficient regulatory measures. On the other hand, other EU members only opened up their markets to the minimum levels required right from the start. It quickly became obvious that equitable competition between market participants could only be possible with two prerequisites:

1. With an equitable 100% opening up of the market for all consumers,
2. With equitable rigorous regulation of the network operators by independent regulatory authorities.

The EU’s acceleration guidelines agreed to in 2003 were designed to ensure fulfilment of precisely these two points. This is to be done by introducing independent regulatory authorities by the year 2004 and to guarantee access to a free electricity market in the EU by the end of 2007.

The above-mentioned rigorous regulatory moves also include greater separation of the distribution network activities from the competitive activities within vertically integrated electricity supply companies. A core element of this separation is their separation under company law. This means that for a certain population size (100,000 customers), a separate network company must be formed. In addition the guideline clearly defines which potential rights remaining holding company (parent company) is allowed to have with regards to the activities of network operator. Basically these rights are limited to being those of a financial investor. Any influence on the daily trading or actual investment decisions must be excluded.
3. Liberalisation of the gas market

The guideline agreed to in 1998 regarding common regulations for the internal EU natural gas market is a regulation similar to that for the internal EU electricity market - on one hand the activities of the competing natural gas companies and, on the other hand, the particular activities of the distribution network operators. In this case the guideline also contains a few provisions regarding the entry of new participants for the delivery and wholesaling of natural gas into the market. Particular problems impacting on the liberalisation of the internal EU gas market are illustrated by two elements:

1. So called Take-or-Pay contracts,
2. Regulation of storage facilities

1: Traditionally, the European gas market has been based upon extremely long-term contracts that have largely been dependent upon imports from Russia. Within the scope of these contracts, the buyer agrees to purchase a certain quantity and the seller can structure the pricing on a variable basis to ensure that natural gas remains competitive with alternative energy sources. Take-or-Pay contracts therefore designate the duty of a buyer to be committed to buying a certain quantity of gas or to pay a defined price for the equivalent amount at the current price. On the basis of these contracts, the liberalisation situation for existing natural gas companies is similar to those for generation plant operators in the electricity market. These contracts can become "Stranded Investments" in the same way such that generation plants are not able to produce electricity competitively.

2: In regard to the coordination of gas storage, discussions in Europe have not produced a clear classification. On one hand gas storage serves to even out pressure variations in the transmission system. On the other hand, this gas storage also serves to compensate for the highly variable demand structure in western European consuming countries. In the first instance, gas storage is connected more with a regulated distribution network company. In the second case it is connected more to the competitive gas market. Because historically, both services cannot be clearly separated from each other, there have been interim regulations in the form of so called negotiated access. Upon the basis of the guidelines, this enables a limitation on regulation of storage services required for the distribution network. Separation of the two areas is technically very complicated to achieve. The findings from the first years of European gas market liberalisation are similar to those for electricity liberalisation. These are that, as well as totally opening up the market, rigorous distribution network tariff regulation is also essential to ensure efficient competition exists.
Introduction
On the 13th of October 2003, the emission trading directive (RL 2003/87/EG) came into force. The central theme of the directive: From 2005, operators of plants in energy intensive industries and energy supply companies have an emissions certificate that corresponds to the scale of their emissions. The certificates are issued by the EU nation states and are tradeable. Emission trading should have the effect of reducing the greenhouse gas emissions in the targetted sectors in line with the national climate targets at commercially justifiable cost levels.

Participants in emission trading

The threshold values stated below generally apply to production capacities or outputs. If an operating company carries out several activities under the same name in a plant or at a location, the capacities of these activities are added together.

<table>
<thead>
<tr>
<th>Activities</th>
<th>Greenhouse gasses</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Energy conversion and transformation</strong></td>
<td></td>
</tr>
<tr>
<td>Furnace units with a furnace heat output of more than 20 MW (excepting plants for the burning of hazardous or domestic waste)</td>
<td>Carbon dioxide</td>
</tr>
<tr>
<td>Mineral oil refineries</td>
<td>Carbon dioxide</td>
</tr>
<tr>
<td>Coking plants</td>
<td>Carbon dioxide</td>
</tr>
<tr>
<td><strong>Iron smelting and processing</strong></td>
<td></td>
</tr>
<tr>
<td>Roasting and sinter plants for iron ore (including sulphide ores)</td>
<td>Carbon dioxide</td>
</tr>
<tr>
<td>Plants for the manufacture of raw iron or steel (primary or secondary smelting operations), including line pouring with a capacity greater than 2.5 tonnes per hour</td>
<td>Carbon dioxide</td>
</tr>
<tr>
<td><strong>Mineral processing industry</strong></td>
<td></td>
</tr>
<tr>
<td>Plants for the manufacture of cement clinker in rotating tube kilns with a production capacity of more than 500 tonnes per day or of lime in rotation tube kilns with a production capacity of more than 50 tonnes per day or in other kilns with a production capacity of more than 50 tonnes per day</td>
<td>Carbon dioxide</td>
</tr>
<tr>
<td><strong>Plants for the manufacture of glass including fibre glass with a smelting capacity of over 20 tonnes per day</strong></td>
<td>Carbon dioxide</td>
</tr>
<tr>
<td>Plants for the manufacture of ceramic products by firing (in particular roof tiles, cellular bricks, furnace bricks, paving tiles, pottery or porcelain) with a production capacity of more than 75 tonnes per day and/or a kiln capacity of more than 4 m$^3$ and a stocking level of more than 300 kg/m$^3$</td>
<td>Carbon dioxide</td>
</tr>
</tbody>
</table>
Miscellaneous industrial branches

Industrial plants for the manufacture of
a) cellulose from wood and other fibrous materials  
   Carbon dioxide

b) Paper and cardboard with a production capacity of more 
   than 20 tonnes per day  
   Carbon dioxide

Plants or parts of plants that are used for the purpose of research and development 
and the testing of new products and processes do not fall under this directive.

Contents of the emission trading directive

- Scheduling into trading periods: 2005 until 2007, 2008 until 2012, further 5 year 
  periods
- In the first period, only trading and reduction obligations for CO₂ later for all 
  greenhouse gasses
- Operations in all the above named branches **must** participate in emission trading
- Operations that are affected obtain permits and emission allowance certificates 
  from the national authorities
- The permit basically authorises the operation to issue emissions. They relate only 
  to the operation for which they were acquired.
- The member states can allow plant operators to establish asset funds within a 
  particular activity area. All the rights and obligations of the combined plants that 
  arise as a result of emission trading are handled through an appointed trustee.
- The operator must possess sufficient certificates to cover their existing emission 
  levels.
- The allocation of certificates takes place based upon a national allocation plan. For 
  the first period, the national allocation plan is to be completed by March 31, 2004.
- The allocation of the certificates for the first period in Austria took place at no cost.
- At the end of each year, the actual emission certificates must be returned to the 
  appropriate authorities (up until April 30th of the following year).
- Participants can freely trade the certificates between each other (EU wide 
  including the acceding countries).
- In order to be able to comply with the return obligations, allocated licences, 
  certificates which are bought, and emission reduction units from JI and CDM 
  projects (the "Linkage Directive" – currently in the draft phase – defines the exact 
  modality) can be used as permitted by the allocation plan
- If the operation does not have sufficient certificates on hand to fulfil the reduction 
  obligations, a penalty of € 40 per tonne of CO₂ in the first trading period and a 
  penalty of € 100 per tonne of CO₂ in the following period must be paid.
- Up until September 30, 2003, the guidelines for monitoring and reporting in regard 
  to emissions should have been made public through the Commission. These 
  cover how the monitoring rules for all the activities affected, and a definition of 
  biomass as defined by the directive, should be applied. At the moment this is a just 
  a proposal.
- A register is being set up to keep track of the allocation, ownership, transfer and 
  cancellation of certificates.
Energy-contracting for efficiency!

Provision of services in business
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Businesses need energy services...

Normally a business takes care of the provision of energy services such process heat or the heating and illumination of rooms itself. Electricity and fuel are bought in as are any technological investments required. An in-house team takes care of the smooth running of the plant. For maintenance services an external partner is contracted.

In this way the secure provision of energy services is guaranteed. But are these services supplied at the lowest possible cost? Is there perhaps potential for a reduction in detrimental environmental effects?

In many sectors the energy costs are just 1 to 3 % of total costs. In times of increasing competitive pressure, it can be of considerable interest to closely examine even the small cost components. In addition, average values don’t apply to every individual company! In many cases, the energy cost component and its significance to any particular company may also be larger.

Energy costs also reduce operating profits. A survey of 11 joineries found that the energy costs reduced the earnings before tax by 15% on average. A - not unrealistic - reduction in energy costs of a third would increase profitability by about 5%.

Diagram 1: Operational cost structure in the production area
... and have increased earnings as a result of the efficient use of energy!

Here are some further examples:

- A wholesale company managed to achieve a reduction in gas consumption of 34% (34,000 m³) and a reduction in the consumption of electricity of 18% (147,600 kWh) – and therefore the associated operational costs.

- A one-off investment of 110,000 ATS in a dairy factory resulted in the realisation of annual energy cost savings of about 190,000 ATS.

- A cogeneration unit was installed in a hotel. The result: a reduction in the annual energy costs by more than 400,000 ATS and a reduction in emissions by about 30%.

- In the process of doing an energy analysis project, a manufacturer of special machinery also carried out a material flow analysis. The starting point focused on network problems experienced at the time of doing commissioning tests. Apart from a dramatic reduction in energy costs achieved due to the installation of a loading management system, the company’s wastewater and rubbish situation was also significantly improved. And as an aside, requests for operational upgrading have since met far less opposition from authorities.

Efficient energy use can have positive additional effects in addition to the relatively small costs for the provision of energy services. Further examples include:

- In a dairy factory, modification of the chemical cleaning process reduced the amount of water needed by about 6%, the amount of alkali by about 46%, and the amount of acid by 34%. The starting point was a decision to pursue a process of active energy management.

- A grocery supermarket achieved a savings of 26% in electricity usage since it changed over to energy-efficient freezers.

- As a result of receiving practical energy and environmental consulting advice, a brewery decided to also improve its quality management. By referring to its resource protection based production processes, the beer is can now be marketed as a high-end quality product.

- A large mail-order business was able to reduce its energy costs by 50% through improved lighting in its warehouses. The staff benefited by having more pleasant working conditions. The new lights no longer caused glare problems.

- A municipal construction company now enjoys the image of being a “clean” company since optimising the energy input into its fleet of cars and material logistics system.

As these practical examples demonstrate, a potential for improvement often exists. In many cases this fact also known within companies but either a lack of time does not permit the capturing of these potential savings or scarce financial resources need to be used for other purposes.
It is in this area that energy contracting offers a solution. For energy contracting, an external partner specialised in the field of efficient energy supplies becomes involved.

**Contracting – how does it work?**

Energy contracting can be differentiated into two forms. If the main concern is supply we talk about plant or utilised energy contracting. In the case of savings contracting, the main objective is generally to better use the energy inputs.

**Plant Contracting**

In the case of plant contracting, an energy services enterprise (ESE) invests in an energy conversion plant on behalf of the client. Example: the ESE installs a cogeneration unit in an industrial operation and acts as the supplier of heat and electricity. The ESE takes care of the fuel supply required. The external partner is also responsible for operational management and maintenance. Financial settlement is based upon the amount of heat and electricity delivered.

The outsourcing of tasks is of particular interest to a company if it sees there is an advantage in doing so – such as a reduction in the costs for providing a supply of energy services or relieving the pressures on operational staff.

**Savings Contracting**

A savings contracting project can include all kinds of efficiency increasing measures. The only and most important basic condition: Those measures must be paid for out of the energy cost savings within a specified time frame. On the other hand a reverse view can be taken: Because the contracting partner’s services will be paid out of the energy cost savings, the customer does not face any additional costs.

The implementation of energy savings measures is the prime focus. However, savings contracting goes even further. The contracting company also identifies and does the planning for the appropriate measures as well as taking over advance financing. Furthermore, savings contracting includes maintenance and upkeep services and energy consumption monitoring. Planned maintenance and prompt feedback regarding energy consumption are guarantees of efficient and cost effective energy use.

Diagram 2 illustrates clearly the effect of savings contracting. Without energy saving investments it is most likely that an increase in the energy costs will need to be allowed for long term. Energy saving measures immediately reduce energy consumption and the associated energy costs. In addition it also has a direct effect by reducing adverse impacts on the environment.
During the term of the contract, the energy costs saved go either partly or fully to the contracting partner. This is laid out in an agreement. In this regard it is important to understand that greater participation by the client toward the cost savings either prolongs the term of the contract or reduces the scope of the package of measures that can be implemented.

The payment to the contracting-partner is reimbursement for all his services, not only investment measures but also maintenance services and operational management. As already mentioned, this is at no cost to the client. After the completion of the usual contract term (usually 5-10 years), the client then profits by up to 100% from the ongoing low costs brought about by the low energy consumption.

Diagram 2: Effectiveness of savings contracting. If desired, the client may participate in the energy cost savings right from the beginning.

If you like, savings contracting can also be viewed as an insurance against changes in energy prices. Increasing energy prices have a lesser impact on a company if energy is used as efficiently as possible and the energy draw-off is not greater than that needed.

As part of its service the contracting-company also provides a savings guarantee. The customer is given a guarantee that the measures to be implemented will actually lead to the successful achievement of the agreed level of savings. In exchange the contracting partner’s payment is dependent upon this success. If the savings do not reach the guaranteed levels, the payment to the contracting-partner will be less.

An interesting option could also be to include savings contracting within an all-encompassing package of improvement measures. The advantage: the company need only make a partial payment instead of paying for all the implementation costs.
Savings contracting can also be customised. The customer should actively contribute his expectations and ideas to the project. In this way a project can be conceived that is best tailored to suit his needs - more about this in the section titled “Tangible steps towards savings contracting within a company”

Incidentally, in practice the reactions can be quite different. In many companies proposals from specialists regarding the implementation of efficiency raising measures through savings contracting are often met with hesitation. However, often the opposite can also be experienced. Many of those in positions of responsibility are pleased that the opportunity for an improvement is on offer (which they have perhaps suggested for quite some time themselves) and can now finally be implemented jointly with an external partner. Often the capital repayment period for an energy savings investment is not of a short enough duration and cannot be justified within the company’s internal specifications. For contracting parties, long-term refinancing time frames are not unusual.

Is all of this too good to be true? Naturally there are also challenges associated with a savings contracting project. This brochure also provides information about these and demonstrates how these challenges can be meet.

**Savings contracting also poses challenges...**

What are the biggest challenges associated with savings contracting? As is often the case, there is no simple answer to this question.

**... take for example the conscious decision to go for long-term cooperation with an external partner...**

The decision to trust an outside partner with a task previously done yourself is often difficult and, as practical experience shows, is often impossible to overcome.

A partner will also develop new solutions that, until now, were unknown to the company. It is for exactly this reason savings specialists are available. Our society today is highly organised around the division of labour. There are specialists for different areas including energy savings. A lack of information with regard to potential improvements is only one possible reason as to why more energy is used than necessary.

With savings contracting, the possibility to optimise the energy use within the company in conjunction with just one lead party now becomes available. In advance of this, a decision must be made in favour of an “energy efficiency partnership”.

**... to prepare for that you should take your time.**

If a decision in favour of savings contracting is made, the next step is to find a capable project partner. Before setting the seal on an energy efficiency partnership, several contractors should first be examined more closely.
The contracting company also has a great interest in knowing in advance the energy savings potential within the company as accurately as possible. This is understandable as the contractor’s performance payments are paid out of the energy cost savings.

In the preparation stages for an energy efficiency partnership, there needs to be a certain amount of input from both sides. This input can be quite extensive if numerous energy consuming units and components are to be included in the project. On the other hand, an all-encompassing project has an advantage because, together with just one lead party, large savings potentials can be attained. Such issues things need to be carefully weighed up.

Independently of the decision regarding the extent of the project, a first rough estimate of the potential value of a savings contracting project is usually carried out by the bidding contractor without charge. If a serious decision is made to proceed with the project, a savings contracting bid needs to be worked out. For this work no costs are incurred so long as the contract is won as a consequence. The energy costs saved can then be converted into revenue for the project services. Naturally, that is only of relevance to the partner who wins the contract. The contractor who misses out will not gain any income from the savings contracting project.

One recommendation (for this see the section “Tangible steps towards an saving contracting project in your company”): The more data and information that is made available for contractors to work out their rough estimates, the easier it becomes for them. It also saves more of your time in answering questions and provides the support the contracting company needs for the necessary estimates and surveys on site. For this reason it is recommended that all available energy relevant reports and information be drawn together and given to the savings specialist for working out a rough estimate. Of particular importance are records relating to energy use, up to date plans for the relevant energy units and, if available, reports relating to previous investigations. The rough estimate will enable initial conclusions to be made regarding the performance capability of a contractor.

As an example, the following can be agreed to with three particularly well qualified contractors. The contractors selected work through a detailed analysis and receive a sum to cover the planning costs that they have incurred - but only in the case where they are not chosen as the energy efficiency partner. Planning for the energy saving measures is included in the offer of services from the savings contracting project partner.

The level of cost reimbursement for the unsuccessful contractor is dependent upon the planning work and the scope of the planned project. Naturally, this is a matter for negotiation.

One important aspect: If several parties are contracted to collaborate in the detailed planning area, the client has a useful advantage by having competition for both price and ideas.
Energy contracting for efficiency! Provision of services in business

The resulting financial advantages are weighed up having regard to the general cost balance of the contracting project. Cost savings in the area of maintenance can also be achieved. Maintenance services for newly installed or upgraded plants are one of the tasks for the contracting company and will be paid out of the energy cost savings. Old plant that has been replaced as a consequence of the project normally would also have incurred maintenance costs that now become a saving for the operational area.

If one invests in preparation that identifies all the cost savings the project can bring about, the total cost balance for the project will potentially be positive after a short period of time. Public building projects have demonstrated that this can be the case in less than a year. The investment in preparation for an energy partnership can be looked at as an essentially profitable investment. In addition, if energy efficiency measures were to be implemented in a conventional way, planning services for that would also necessary which, as a rule, are integrated into the overall costs.

There are many arguments that can be used against a savings contracting project. The ten most popular ones can be found in an advisory booklet about energy contracting in the area of public real estate\(^1\). Whilst most of the advisory booklet is aimed primarily at public authorities, most of its contents can also be applied to other areas. There is one thing these arguments have in common – for every one of them there is a counter argument.

Savings contracting is certainly not the easiest way for a company to gain energy cost savings and environmental relief. However, it is an alternative worth thinking about because, with a minimal input of personnel and financial resources, measures can be implemented. This guarantees a saving in the costs of operations. In the following sections there is more about how one can develop a precise approach to a savings contracting project.

Incidentally, plant contracting is not a subject covered in this brochure. From the project design view, such large challenges are not associated with plant contracting - in comparison to savings contracting. If the efficiency potential can be largely utilised e.g. in the conversion of natural gas or heating oil to end use energy such as for room heating or the provision of compressed air, a comparatively large part of the savings potential always remains untouched.

By comparison, with savings contracting an important part of the energy cost saving potential can be achieved rapidly. At the same time, savings contracting is the biggest challenge and a comparatively more comprehensive service.

A great deal of information relating plant contracting can be obtained from, for example, the Internet page for the Heat Supply Association (http://www.vfw.de). The contact address of the Heat Supply Association in Austria can be find in the service reference section in this brochure.

Tangible steps towards savings contracting in your own company

What is the best starting point if, with the help of savings contracting, the energy use within any company is to be optimised and the costs and emissions reduced?

Simply allow several savings contracting companies to put together bids and then choose the most interesting one.

The first rough estimate that assesses the viability of the project is normally done at no cost. The working out of an exact offer for a savings contracting project needs to include the appropriate planning services and can be more complex. If a contract is not won, the contractor cannot derive any revenue for his work out of the savings contracting project. He will therefore have a strong interest as to whether he can claim some sort of contribution towards covering these planning costs in the event he does not become the energy efficiency partner.

It must be reiterated that, from the client’s perspective, the investment in the preparation of an energy efficiency partnership can be viewed as positive investment - so long as one looks at the overall balance.

Perhaps at this stage you would like to have further background information so that you can ask the contracting company the appropriate questions regarding their proposition. Or the client would like to be actively involved in the design of the savings contracting project. If this is the case, you should carry on reading!

In the following text, a possible approach towards a savings contracting project within your company is demonstrated step by step.

Step 1: Feasibility assessment and selecting the project basis

Before investing unnecessary sums of money and time into the preparation of a savings contracting project, it is naturally of interest to know whether it can be realistically implemented.

It is best to ask a specialist about this and to approach one or perhaps several qualified contractors\(^2\) to have a look at the company and provide a rough estimate as to whether a savings contracting project would be of any positive value.

If a contractor has an interest in the project, he will supply preliminary input without asking for payment. A contractor will be more inclined to give a preliminary input without cost provided that the associated investment is not too great. The client can assist by making all the information relating to the relevant plant units and installations available.

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\(^2\) Addresses of contractors – for example you can find these in the index of contractors in Austria: http://www.eva.ac.at/contracting/index.htm
Which plant and installations are important in this regard? Or, in the more general sense, ask what can be optimised by means of savings contracting? The issue can also be clarified through discussions with savings specialists.

As a general rule, all improvements that can be paid for out of energy cost savings within a clear time frame are suitable for a savings contracting project – meaning all economically viable savings measures.

The exact assessment of the cost effectiveness of improvement measures requires information relating to the associated implementation costs and the potential reductions in energy consumption attainable. An economic viability calculation can be comparatively expensive.

However, is it necessary to do a rough estimate as to whether a savings contracting project can be implemented in the client’s operations and must the company really be subjected to a detailed examination regarding the economics of savings measures? The answer is short and sharp – no! In this phase it is more important to estimate whether a savings contracting project makes any sense at all and which plant and installations need to be included in the project. An experienced contractor has the knowledge to do that without having to undertake a comprehensive savings analysis.

How can one figure out which energy uses need to be included in the savings contracting project? In that regard four questions can be useful:

1. Which plant and components, according to experience, offer a large enough potential for improvement?

   Apart from units that supply energy services such as heating or lighting of rooms, economic savings can be also be expected for installations that are directly associated with production processes.

   A study found that the costs of providing room heating in the industrial sector could be reduced by about 14 % if only economically viable savings measures were to be implemented. In the area of process heat and for electric motors, the savings potentials would have been about 17 % and 15 % respectively.³

   By means of optimised process control, energy costs can be reduced by about 5 to 10 %. On the basis of experience, the energy cost savings potential associated with product drying and heat recovery is between 5 and 40 %. Naturally, this depends upon the initial situation.

   Thus: Economically viable cost savings can basically be achieved within all energy using facilities, plants and components. The more comprehensive the savings contracting project is, the sooner the improvements can be implemented that, when looked at in isolation, would not be economic. This means that less economically viable improvements can be cross-subsidised by those with greater economic viability within a package of measures.

³ E.V.A. (Publisher): LCP in Austria. Final report Vienna 1996 - www.eva.ac.at/projekte/lcp.htm
For this reason, no energy use area within a company should be excluded at the start if a comprehensive savings contracting project is to be defined.

2. Is the plant and are the installations at the latest technological level?

If all or the greatest part of the plant has recently been installed or raised to the latest technological standards, then it is likely that the replacement of these units could not be fully financed from the energy cost savings - apart from the fact of whether it is logical.

In this case, experience suggests that the potential for improvements lies more in the area of optimisation and the improved alignment of differing energy uses to each other. The energy savings functions of plant are often not – or at least after a certain period of time no longer – fully utilised.

Experiences with savings contracting in the building area have shown that in nearly every building a savings potential can be found which can be developed in a more economical way. This is also true for new buildings or for properties that have been recently renovated. Incidentally, if during the course of working out a rough estimate it becomes clear that there is no economically viable potential for improvement, such information can also be of interest to the staff responsible.

In general it can be said that the modernisation of older plant, and in same cases its replacement, can often be argued for within the magnitude of the energy cost savings made. For new plant, possible optimisation potential might possibly exist which can be mobilised during the course of the savings contracting project.

3. Can the project basis be defined?

This question is always important when a savings contracting project is not restricted to one object as a whole. It is then necessary to determine the savings for the plant and installations which are to be included in the energy efficiency partnership e.g. ascertained with the assistance of suitable measuring devices. The project purpose must then be able to be defined. In this way, the savings identified by the savings specialist can be precisely calculated. Both contract parties have an interest in doing this because the payments to the contracting company are based upon the energy cost savings.

This is shown on the following example. An external savings specialist has optimised the complete ventilation system in a private clinic. The energy costs saved and the associated payment to the contracting partner is calculated on the number of operating hours for this plant. Thus the basis for the project has been separated out from the total system and the contracting–partner is paid based upon the cost savings achieved through the measures he implemented.
4. Is the inclusion of certain plant and facilities not desirable or not useful?

Perhaps the client wants selected plant and installations to be taken care have by one particular partner and therefore don’t want to include them in a project.

On the other hand, a savings specialist might also recommend that a certain energy application not be included in the project because he doesn’t have the required optimisation know-how and can’t access it within the time available.

After discussions about these questions, it will perhaps now become somewhat clearer about those items that should realistically be included in the project. If an all-embracing project is specified, generally no energy application is excluded at the start – even if it is just a matter of increasing optimisation through better coordination. It is more likely that certain plant and installations will be excluded because it is the wish of either the client or contractor.

The relevant energy applications can now be specified - if necessary together with the saving specialist. For the plant and installations selected, all the available papers and data should be put together and handed over to the contractor as the basis for doing a rough estimate. In this regard include data about energy use, and possible up-to-date plans and, if available, certification relating to surveys already carried out in particular.

If the outcome of the rough estimate shows that a savings contracting project is of value, that means there is a green light to proceed with an energy efficiency partnership.

**Step 2: Setting up the frameworks**

Savings contracting can be customised. The project can be fine tuned to exactly meet the needs of real situations. If one wants to use the latitude available for customisation then one should consider the frameworks within which one wishes to allow the energy specialist to work for an energy efficiency partnership. In this way the client can actively influence the customisation of the project.

A desirable additional consideration: It is easier to compare various contract bids if they are all based on the same specifications from the client.

In particular it is worth considering the following aspects:

*Contract term*

The longer the time frame available for amortisation of the investment costs, the sooner less economic energy savings investments can be incorporated into the project. It has been observed that companies often hold back when it comes to long-term contracts. The for and against arguments associated with long term contracts need to be weighed up.
**Scope of services**

As a rule, the contractor’s service package for savings contracting includes, other than identification, planning and implementation of the improvement measures, also their financing as well as additional services such as operational control, maintenance and monitoring of energy use. The contracting party will be paid out of the energy cost savings.

For the project calculations, it is important for the energy efficiency partner to know if all the associated tasks in this connection need to be fulfilled. This is especially so for the maintenance area and the sub-components of inspection, upkeep and repairs. It appears sensible to hand over to the contracting partner full responsibility for maintenance of all those assembly units and plants that are subject to improvement measures by that contracting partner. In this way, discussions about who has responsibility won’t arise.

There is a possibility that the client is interested in the contracting partner taking over the maintenance tasks for existing plant and to pay for the associated services out of the energy cost savings. The money paid to cover maintenance services out of the energy cost savings envisaged means however, that it cannot be used for the refinancing of energy savings investments.

Measures that have a lower economic value would then not be included in the package of measures. Independently of that, each case needs to be examined on its own in order to decide whether it makes sense to pay for the maintenance costs associated with older plant assets out of the energy cost savings.

One idea with regard to the issue of maintenance is that the contractor basically takes over inspection and maintenance, but only takes over upgrading for the new plant and components that the contractor has put in.

**Product quality**

The task of maintenance for the newly introduced plant and components is normally the responsibility of the energy efficiency partner. He will take this into consideration when selecting the products and quality which are to be used. In addition, the contractor also has a strong interest in the reliability of the components used because only faultless functioning ensures the successful achievement of savings.

However, the client might wish to provide the contractor with guidelines that define the quality of products that are to be used.

**Change of energy source**

It is possible that a company has undertaken to continuously reduce emissions through the introduction of an environmental management system. The energy efficiency partnership contributes its part by mobilising the economic saving potentials. An additional reduction in emissions can be achieved by the introduction of a form of energy that lowers emissions by the contracting party.
On the other hand, the job specifications can be formulated so that they state that a change in the energy source may only occur provided there are no negative effects on the environment. The contractor can prove this with the assistance of an emissions balance. To do this a calculation process and the emission factors for the relevant materials need to be provided.

Comfort of Use
The lowering of excessive comfort levels leads to reduced operational costs. An adequate level of comfort still needs to be assured. It is recommended that the contractor takes into account comfort parameters such as room temperature, rate of air exchange, and illumination strength and their compliance with the corresponding standards and guidelines.

Investment cost grants
With savings contracting, economically viable energy savings measures can be implemented. In addition, a possibility of cross-subsidising measures with lower economic viability within the package of measures also exists.

However, such less economically justifiable measures can certainly be included in the project if the client pays for part of the costs that will be incurred as a result of implementing these measures. The decision to partly pay for the costs of these measure needs to be made known to the contractor as it is an important condition within the project framework for the contractor’s bid calculations.

Consistent guidelines relating to the above-mentioned areas make it easier to compare several different contract bids. Naturally an important aspect in this regard is also the content of the energy savings contract that is to be concluded with the bidder. Proper comparison of the contract bids is only possible if they all are based on the same contract text.

Step 3: Obtaining bids and evaluating
The result of a rough estimate indicates that a savings contracting project is basically possible and that thinking about the project form has also led to this conclusion.

It is now necessary to select the best contractors for your company for an energy efficiency partnership.

You can proceed as follows: First put together a request for a quotation with information and data relating to the following areas:

- Project basis

The energy consuming equipment that is to be included in the energy efficiency partnership. These need to be designated and any available information such as energy supply data, up-to-date plans and applicable energy reports need to be added to the request for a quotation.
Extent of services

A description of the services that the savings specialist should take over in the course of the project along with specification of the of desired interfaces in the area of maintenance;

- Basic conditions
  The important basic conditions to be borne in mind at time of compiling bids need to be disclosed. For example, these include the contract term, product quality specifications, and a statement of whether it is possible to include investment cost grants into the project calculations.

- Energy savings contract
  The energy savings contract, or at least the pre-formulated sections that one as the client wants to have included in the contract, can be predetermined.

Selected contractors can then be sent the request for a quotation and asked to develop a response, for example with one or several of the companies with which the company has already worked whilst putting together the rough estimate - if they have proven themselves to be competent partners.

With regard to choosing the bidder, one should also think about businesses that can provide the appropriate references. It is also recommended to get in touch with those who have already had experience as clients with savings contracting projects4.

One should discuss the conditions for putting together a quotation with the bidders under consideration.

A little background information as a orientation guide: The effort required for putting together a quotation for a savings contracting project can be relatively large. The contractor has the incentive to estimate as accurately as possible the potential savings that can be targeted by a package of measures. On one hand he must guarantee that the specified cost savings can actually be achieved and, on the other hand, he must consider his competitive position relative to other bidders.

The extent of planning services required depends particularly upon what the project encompasses. An example: The energy efficiency partnership is limited to the supply of energy services to optimise the heating and lighting of rooms in the administration building. In this case, the effort required for compiling the contract bid is justifiable. An experienced contractor can draw on his experience and the appropriate hand tools. He then calculates a savings guarantee without having to bring in expensive development planning services. This is conditional upon the relevant information and data being made available.

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4 Examples of projects with contact persons can be found in the index of contractors in Austria: http://www.eva.ac.at/contracting/index.htm
A different situation: A comprehensive energy efficiency partnership is to be defined and, in this regard, optimisation of the operation of production facilities is to be included. In this case, putting together of a bid will require greater investment – for one reason because of the greater scope of the project and, for another, because until today most contracting parties still have limited experience in confidently estimating the savings potentials that are associated with energy technology based optimisation of production facilities. Thus the compilation of a bid can require a corresponding input from development planning service groups and that might include its assignment to a subcontractor.

Depending upon the designated scope of the energy efficiency partnership, it is now appropriate to negotiate a contribution to cover the costs of putting together a quotation with the contracting company - but only in the case where the contractor fails to win the contract. Otherwise, the costs for planning services can be recovered from the energy cost savings. Naturally, the agreement of conditions for compiling the bid is also a matter for negotiation.

A concluding thought in this regard: If optimisation measures are to be implemented, then the costs are associated with the planning. In the case of savings contracting, the client gains the additional guarantee of cost savings.

Finally, the bids on offer need to be checked through and evaluated. An important criteria that needs to be considered is level the of the savings guarantee. Perhaps there is a desire to include additional evaluation parameters or criteria into the bid evaluation process e.g. statements of the internal guidelines for assessing suppliers.

Step 4: The energy efficiency partnership commences

When the decision relating to a project partner has been made, the energy efficiency partnership can commence! If the project is understood to be a partnership by both parties and a basic preparedness for getting results exists then nothing stands in the way of the project’s success.

There have already been numerous examples of positive experiences with energy efficiency partnerships, especially in the area of public buildings.

The first few savings contracting projects in Austria in the market segment, "industrial firms" have had the exploitation of the potential for increased efficiency in the areas of supply of room heating and illumination as their prime aim.

For example, in a wholesale centre using a diverse mix of measures implemented within a savings contracting project, satisfactory results were achieved: electricity savings of 7.5%, heating 18%, peak loading capacities 14%. This led to a reduction of annual operating costs of more than 1 mio. ATS.
Information sources

▶ Reference addresses for the contractor index - contracting

*as PDF-Download:

http://www.eva.ac.at/contracting/index.htm

*In print form*

Energy recycling agency – the Austrian Energy Agency (E.V.A.)

ADR: Otto-Bauer-Gasse 6, A-1060 Wien  
Tel: +43-(0) 1 5861524 / Fax: 5861524-40  
eva@eva.ac.at  
http://www.eva.ac.at

▶ Reference addresses for diverse publications regarding energy contracting

Energy Tirol

ADR: Adamgasse 4, A-6020 Innsbruck  
Tel: +43-(0)512 589913 / Fax: 589913-30  
energie@tirol.at  
http://www.tirol.com/energie-tirol

Energy recycling agency – the Austrian Energy Agency (E.V.A.)

ADR: Otto-Bauer-Gasse 6, A-1060 Wien  
Tel: +43-(0)1 5861524 / Fax: 5861524-40  
eva@eva.ac.at  
http://www.eva.ac.at

ÖBU

Swiss union for ecological conscious company management

ADR: Obstgartenstrasse 28, CH - 8035 Zürich  
Tel: +41-(0)1 364 37 38 / Fax: 364 37 11  
oebuinfo@oebu.ch

Federal environmental agency

ADR: Postfach 33 00 22, D - 14191 Berlin  
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Contact person for professional and technical questions relating to savings contracting

Energy Tirol
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- energie@tirol.at
- http://www.tirol.com/energie-tirol

Energy agency Waldviertel
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- +43-(0)2842 9025 40871 / Fax: 9025 40870
- energieagentur@wvnet.at

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- eva@eva.ac.at
- http://www.eva.ac.at

Grazer Energy agency - GEA
- Kaiserfeldgasse 13, A-8010 Graz
- +43-(0)316 811848-0 / Fax: 811848-9
- office@grazer-ea.at

Contact people for legal questions

Austrian chamber of lawyers
- Rotenturmstraße 13, A-1010 Wien
- +43-(0)1 5351275 / Fax: 5320473

Contact person regarding subsidies and grants

Kommunalkredit Austria AG
- Türkenstraße 9, A-1092 Wien
- +43-(0)1 31631-0 / Fax: 31631-105
- kommunal@kommunalkredit.at
- http://www.kommunalkredit.at
Contact partner regarding efficient energy use

BEA - Burgenländische Energieagentur
- Technologiezentrum Eisenstadt, Marktstraße 3, A-7000 Eisenstadt
- +43-(0)2682 704-2220 / Fax: 704-2210
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- +43-(0)3572 44670-0 / Fax: 44670-25
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**Salzburg (Amt der Salzburger Landesregierung)**

- Abteilung 15, Postfach 527, A-5010 Salzburg
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▶ Literature


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Introduction
Process management is an important tool that makes it possible to measure the applicable variables within a process in real time, to compare the values, and to actively manage the process.
The advantages of a process management system are:

- Measurement of throughput and
- Measurement of effectiveness
- Analysis of the network quality

This section is divided into three parts:
- Field Equipment
- Monitoring
- Management

Levels in a process management system
The hierarchical structure of a process management system provides for the specific delegation of tasks and functions relating to the differing automation levels. In a modern company the process management system may consist of numerous levels. A classic breakdown is illustrated below:

Management level
Automation level
Field level
1. Field level
The field level is the most basic level at which various use-related equipment operates. The tasks comprise the following:

- For determining the plant status by means of sensors

  ![](sensors.png)

  **Sensors**

- And for influencing the status of plant by the operation of actuators

  ![](actuators.png)

  **Actuators**

Field level devices may produce either analogue or digital signals. These need to be differentiated when considering signal output and signal reception.

**Analogue signals**
Sensors producing analogue signals are normally used for measuring values such as temperature, pressure, moisture, flow rate, as well as for the reporting of the position of positioning motors through signal reception and continuously driven positioning devices through signal output.

**Digital signals**
These signals have an on/off characteristic. On the reporting side they can indicate a disruption has occurred or that the status signal is normal. On the controlling side they may mean, switch on or switch off a single piece of equipment or the entire production line.
Data points
The generic term for these signals is the “data point”. Both analogue and digital data points physically exist.
There are also further variants and these are virtual data points. These points do not physically exist within the system – they cannot be physically touched or directly measured. They serve the purpose of better capturing and processing the status within an operating sequence. For example, where two digital input signals are combined into one logical result, an additional virtual digital data point is created.

2. Automation level
The processing units at the automation level are DDC automation stations. An automation station consists of:

- a microprocessor and
- input/output units

The physical data points are picked up by the input/output units and made available to the microprocessor. Within the microprocessor, appropriate software runs so, that in conjunction with the input/output units, a completely functional unit exists. The software must be developed by experienced programmers who not only possess skills in software programming but also knowledge of the types of units required.

The tasks of automation stations in detail:
- Cyclical logging of the process signals and the corresponding output. This is a very important assessment criterion. If the programme cycle duration lasts longer than the particular process on site, then the outcome will be that the plant will never function efficiently!

- Controlling, regulating and calculative processing functions are carried out by the DDC system. It must be appreciated that not all systems available on the market are able carry out all the necessary mathematical functions. For this reason problems can arise with some applications if the relevant procedures cannot be represented mathematically within the programme.

- Processing functions are modular programme building blocks available from a manufacturer. This means that not everything has to be programmed for each plant unit and that individual programming components can be accessed directly. In this area differences also exist as to whether a system is freely programmable or can be freely parameterised. A higher degree of latitude is available with systems that are freely programmable.
Optimisation functions
In order to have a cost saving control technology installed, it is important to check the capabilities that the system offers. There are many optimisation functions that can be used in various areas of process automation. It is important to compare the individual systems available for this purpose and weigh up the associated possibilities for their use.
The following functions are examples suited to process automation:
- Free (night) cooling
- Optimum start/stop
- Cooling down protection
- Flexible switching
- Intermittent duty
- Soft start-up

Manual servicing level
Because automation stations must continue functioning when the central control system fails and thus must be able to be operated independently, the potential for manual servicing at the automation station level must be allowed for.
By means of this manual servicing level, output signals can be provided by hand e.g. for switching on a unit.
What happens at the manual servicing level must be reported back to the automation station so that during normal operations it can simply be seen whether a manual intervention has taken place. Manual interventions are displayed visually at the automation level by the use of lights. This ensures that a quick overview of what has been happening is available.

Observation unit/service display
A service display must be connected at the automation station. By this means, fast access to the programme is possible on-site. Any possible adjustments necessary can be dealt with without having any problems. It is therefore important for the operator that the service display enables communication in plain language. There are still systems around where the operator must determine an associated instruction by referring to code lists. These systems are now out of date and make the daily job unnecessarily complicated.

The technical potential to access all the connected microprocessors from the service display by means of a bus connection exists with some systems. This means it is not necessary to physically go to each station. This is made possible by distant intervention connections. It should be noted that bus wide servicing requires an appropriate level of knowledge from operating staff. This is essential because the status of the plant can’t be directly observed.
3. Management level
The data accumulating in the automation station is, to a certain extent, transferred over a bus system to the central management centre and used there for central servicing and monitoring of the whole plant.

Operating system
Exotic systems can easily become obsolete and, for this reason, do not have continuous support. Choosing such systems can result in having a system that rapidly becomes out of date because advances in this sector quickly lead to its replacement. Standard operating systems are the preferred option in order to obtain a better service at an acceptable cost and have better interoperability.

Visualisation
The display of plant information – “process visualisation” – takes place by means of a colour monitor or a touch screen. Process visualisation is normally produced by using plant diagrams that have been specially designed for this purpose. This ensures that its operation by the user is as easy and efficient as possible. Current values are displayed on the diagram so that plant status can be quickly ascertained visually. The software should ideally be in a position to display dynamic processes corresponding to the real time situation. Use of the display by operational staff is simplified further if the plant status is clearly displayed by using different colours for different states.

Trends
So-called trends can be designed in order to document the pattern of plant performance. In this way the continuous optimisation of a process becomes possible. As an additional benefit, using trends can lead to the achievement of an improved result at a lower cost input. Analysis of the trends should also be carried out using standard software in order to facilitate simple processing of the data. This is because the data alone are of little value. For this reason the potential to be able to work in an interdisciplinary fashion must exist between the technical and operational departments.

Alarm memory
In addition, any alarms that are set off can be logged by means of an alarm memory. By using this function the plant can be monitored and possible repair work can be carried out before a major problem actually occurs. This is important because making a replacement or substitution at the right time can save a great deal of money. Operational staff can be given an appropriate early warning by the alarm so that as little time as possible is lost due to disruptions. For this purpose, the possibility of passing on an alarm report rapidly by means of a fax, SMS or voice message exists. Through a combination of trend analysis and an alarm memory, possible causes of faults can thus be quickly localised and corrected.
Interfaces
One important point to consider is the openness of the system. The case might be that within an individual company several different automation systems are being used.
However, for the operator it is important that only one visualisation software system is used for servicing, otherwise complexity in the plant is increased unnecessarily. In addition it is also important that data is also available for use in other systems. By taking such an approach, an homogenous overall system can be used on top of a range of differing systems.
In the area of communications the latest technological advance is over OPC interfaces. This technology is based on the OLE function in the Microsoft world and facilitates the simple management of various systems. The majority of large suppliers already have the appropriate interfaces and can thus communicate with each other.
In this area standardisation is also paramount. This results in money being saved and the realisation of improvements in functionality.
1. Basic Principles

1.1 General
For the assessment of measures with regard to their technical efficiency, ecologically moderating effects and, at the same time, economical use of energy, an economic analysis needs to be carried out in order to determine the commercial economic advantages. However, this does not allow for the inclusion of all the advantages of economical energy use in quantitative or monetary terms.

- Economic analyses cannot provide exact values for future costs and benefits. All assumptions, in particular those regarding the future developments in prices and interest rates, are characterised by uncertainties that, as a consequence, produce a corresponding range for the calculated results derived from them.
- Even with methodologically perfect procedures, a comparative economic analysis often cannot provide the basis for a decision between investment alternatives. The results of the commercial economic analyses often lie so close to each other that the deviations lie within the uncertain data related range, which means that economic criteria alone do not enable sensible decision making. Within such alternatives, a decision is thus made using considerations other than economic criteria.
- Many outcomes are not of a type that allow themselves to be valued in full or in part in monetary terms, e.g. improved comfort, simplification of servicing.
- Through lowered energy consumption, the environment becomes correspondingly less polluted. At best, financial valuations are only to some extent possible when society is directly affected.
- National economic criteria are not compelled to be in harmony with business management standards. Consequential social and ecological costs are not taken into account by commercial management analyses. By means of taxes and duties these external costs can be internalized to a degree. However, in principle, it is not possible to undertake a financial assessment of all the future damage.

Commercial economic advantageousness is only one criterion that lies alongside other important standards such as environmental compatibility, national economic valuations or security of supply. Therefore, the latter criteria must have an influence on the decision in the case where various investment alternatives result in commercially economic measures of equal rating.

1.2 Methods of Economic Analysis
In the first instance, investments in energy saving measures must basically be assessed in comparison to the alternative energy costs incurred. As a result these are handled in a different way to investments in production plant where the alternative is for investment in another plant item that has a possibly higher return on capital. In the case of energy saving measures, the comparative costs are fixed: the otherwise unavoidable costs for drawing energy. Every measure that can provide the desired energy service at a lesser cost than the drawing of energy is economic.
In the case of economic analyses over a longer time frame, the interest rate must be taken into account as a fundamental consideration. Dynamic (multi period) methods include these within the analysis in contrast to static (single period) methods. The common methods for economic analyses are:

<table>
<thead>
<tr>
<th>Static Procedures</th>
<th>Dynamic Procedures</th>
</tr>
</thead>
<tbody>
<tr>
<td>Comparative cost analysis</td>
<td>Capital value method</td>
</tr>
<tr>
<td>Cost effectiveness analysis</td>
<td>Internal rate of return</td>
</tr>
<tr>
<td>Amortisation analysis</td>
<td>Annuity method</td>
</tr>
</tbody>
</table>

The static methods of economic analysis are uncomplicated and can be carried out at little expense. However, they permit only limited meaningfulness. The main distinguishing feature and the simplified assumptions associated with this procedure mean that it does not recognize time-based differences for the entering of payments. In the energy area, amortisation analysis is widespread as a static method for making a quick assessment:

**Amortisation time (Pay-back-period)**
Sought: Pay back period
The number of years within which investments are able to be repaid from profits (energy savings). A measure of the degree of the investment related risks. The shorter the pay back period, the more economic the measure becomes. For the assessment of energy technology optimization, it is of only limited suitability because profits accrued after the amortisation period remain unaccounted for. The amortisation time analysis does not allow for any final conclusions regarding the cost effectiveness of the investment. That is why they are used for the assessment of the investment risk, not an assessment of the economics of the investment. The method leads to the preferential rating of solutions that save little energy with minimal investment.

The Dynamic Procedures for Economic Analysis use financial-mathematical methods in order to portray the simplified assumptions used in the static methods in a more realistic way. The main difference is the examination of all the periods that are within the utilisation life of an investment. Payments due at differing points of time are made comparable by means of the addition or subtraction of interest. Example:
A payment of the amount \( X \) at a time point of today, and the same payment in five years time, cannot be the same value as that set today because, for the amount \( X \) in five years time only the amount \( Y \) \((Y<X)\) needs to be invested today which, inclusive of interest profits, will have grown to the amount \( X \) in five years time.

**Capital Value Method:**
Sought: The total costs over the utilisation life
All costs that are incurred during the utilisation life are totaled. At the same time, the costs incurred at a later point in time are not taken into account on their nominal value but on the basis of the amount that one would have had to have invested at the time of starting in order to pay for the later costs. As a result, the capital value is the total amount that needs to be invested which, including interest, covers all the investment and ongoing costs. The goal is to keep the capital value, i.e. the total costs, to the minimum. If not only costs are incurred but revenue is also obtained, then it is the difference between the outgoings and revenue that should be used instead.
Annuity method
Sought: average annual costs
By taking into account interest, the investment is divided into nominally equal payments over the utilisation life. By this means, the costs of the present situation (without investment) and the costs of the optimisation variant (with investment) can be directly compared with each other. The most economic solution is the variant with the lowest total costs per year. The annuity method is the clearest and that is why it is most often used. For training, we will carry out economic analysis on the basis of the annuity method.

2. Cost factors

For an economic analysis, three types of costs decide energy technology investments:

- Capital costs
- Consumption costs
- Operating costs

2.1 Capital costs
The capital costs are the net result of the investment costs, less possible subsidies, multiplied by the corresponding interest factors. The investments required for the components and technical plant are determined from the corresponding cost estimates. Tax rebates, subsidies, interest holidays, etc. are taken into account as reductions in the capital costs.

In the case of a conversion project, the effective cost components connected with the energy consumption are taken into account. One should take particular note that costs that are incurred due to non-energy related redevelopment measures should not be included in the analysis for the energy savings measures. Hence, for the economic analysis, it is only the additional costs, compared to normal redevelopment requirements without energy saving, that are taken into account.

2.2 Consumption Costs
For each energy source, the energy costs are derived from the annual energy consumption multiplied by the energy cost.

2.3 Operating Costs
The costs for maintenance, staff, upkeep and administration are determined on the basis of their maintenance contracts or from experience values.

3. Equivalent Energy Price
Should measures relative to one base variant be compared, e.g. for redevelopment, then the equivalent energy price method is especially advantageous. As above, the total annual costs are derived from the capital costs, the average yearly consumption costs as well as the operating costs. This value is divided by the consumption of utilizable energy. The result in costs per kWh of energy provides a clear comparative value.
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1 Introduction ......................................................................................................................... 2
2 ENERGY MANAGEMENT ................................................................................................. 2
3 General conditions and influencing parameters ............................................................. 4
   3.1.1 Legal conditions ...................................................................................................... 4
4 ORGANISATION ............................................................................................................... 5
   4.1 Data collection and recording .................................................................................... 5
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      4.5.1 Immediate measures ....................................................................................... 7
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1 Introduction

The use of energy in its various forms (motive power, heat, refrigeration, compressed air...) is an important factor in the production process.

The influence of energy costs on product price varies greatly between different areas of industry.

In exactly the same way as for other production costs, energy costs must be recorded and evaluated at all management levels in order to identify the efficiency of its use.

Alongside the operational and cost issues, there are also other important wider aspects that warrant attention.

The finite nature of energy reserves and the effect of energy consumption on the environment are factors that are increasing in significance.

Energy is a scarce commodity. In spite of technological advances that improve equipment efficiency, every organisation is wise to create conditions that lead to energy being used at its optimum efficiency.

It must be clearly understood that energy consumption always has an impact on the environment and the burning of fossil fuels releases additional CO₂.

Because a growing proportion of energy must be imported, the efficient use of energy is an important competitive and national economic issue.

2 ENERGY MANAGEMENT

Energy Management is an activity within a business that co-ordinates the introduction and operation of a system that records energy consumption in a defined process and also monitors whether this energy is being used efficiently. This occurs through the following four steps:

- Definition of the business’s energy goals.
- Development of an energy management strategy
- Motivation of staff with regard to energy issues
- Formulation of a detailed Energy Strategy
The ENERGY MANAGER (EM) is the person responsible for energy management within an organisation. This position is ideally a key position at senior management level. By doing this communication channels to the company’s senior management are kept short.

Further key functions of the ENERGY MANAGER are:

- Dialogue with the organisation’s senior executives in order to incorporate the company goals defined by energy management into quality control management.
- To ensure the organisation complies with changes to energy regulation and legislation.
- To construct an information system so that all the relevant departmental managers are informed at regular intervals regarding the annual goals for energy management as well as the current status of their area of responsibility. The purpose of this is to strengthen co-operation and a feeling of joint responsibility between participants in achieving those goals.
- Regular investigation of energy consumption using checklists.
- Organisation of an Energy Management Working Group made up of participants from within company senior management and production management.

Even though the main duty of the energy manager (EM) is to organise energy consumption as efficiently as possible, economic aspects must also be taken into account.

Because of the varying energy costs associated with different consuming units and the discrepancy between quantities of energy and services ordered and actually consumed, advice from the EM regarding energy purchasing is essential to ensure that the company obtains the most advantageous supply agreements.

The EM must be well informed with regard to grant programmes offered by the EU, central, and local government and advise the company’s senior management with regard to investment measures. The EM should also advise on issues such as Climate Change Levy (CCL) exemption and Enhanced Capital Allowances (ECA’s) and the assistance available from Action Energy.
3 General conditions and influencing parameters

3.1.1 Legal conditions

Due to the importance of energy consumption to the national economy, governments have created frameworks to encourage rational energy utilisation.

The following issues should be noted:

- Energy Efficiency Initiatives
- Energy tariffs
- Emission laws
- General supply conditions
- Laws for the energy industry
- Standards and guidelines
- CO\textsubscript{2} - trading

The IPPC (Integrated Pollution Prevention and Control) regulations are of particular importance.

Climate Change Levy exemption agreements commit sections of industry towards demonstrable energy and CO\textsubscript{2} savings.

Influencing factors

- Energy costs
- Environmental costs for energy consumers such as emission taxes, etc
- Climatic conditions
- Product sales prices
4 ORGANISATION

Organisation of the energy management system is based on the following tools:

- Data collection and recording;
- Energy cost recording;
- Data evaluation;
- Energy audits;
- Measurements;
- Monitoring.

4.1 Data collection and recording

Data collection does not only cover the periodic recording of varying energy consumption by units, but also the collection of production data during the measurement period.

Energy consumption within a business can easily be determined from the energy accounts. However, these do not help in the allocation of consumption to individual consuming units. Within a company there are typically areas, productive and non-productive, in which energy is consumed. In the case of good energy management, energy use surveying takes place upon the basis of logically separated functional areas.

In order to optimise data collection, the use of a checklist is recommended.

For estimating the effectiveness of energy management, energy flow diagrams that allocate energy purchases to individual consuming units have proven to be of value.

4.2 Energy cost logging

When energy cost logging is discussed, it means a data processing system which almost entirely automatically calculates energy consumption, or the proportion consumed for a production process in a relevant physical unit such as kilojoules (kJ=1000 joules), or a specific value established for the energy consumption per production unit. This is undertaken in order to be able to compare these with average values (benchmarking). The Microsoft EXCEL spreadsheets provide an example of one possible format for demonstrating how data should be organised so that the desired outcomes can be achieved.
4.3 Data analysis

A basic prerequisite for analysis is the setting of so-called monitoring targets e.g. the values being sought after. The measured actual values are then compared with previously determined targets.

Following a critical examination of the accuracy of the values, which includes both measurements as well as calculations, results are compared with expected values and any deviation is assessed.

As a next step, a detailed analysis is required so that the potential for improvements can be determined.

This analysis should demonstrate the effects of improvement measures in a spreadsheet within which the calculations and, where measured values are not available, well-based estimates are supplied. Results can be compared with the set targets.

4.4 Energy audits

The energy consuming equipment in a company, particularly in energy intensive industries, and the equipment for converting and distributing energy such as boilers, distribution feeds for compressed air and steam etc., need regular maintenance which is carried out by trained maintenance staff. In addition, the energy efficiency of the plant must be checked regularly.

Energy Audits or specialised studies may be carried out by external consultants. Although the methods required are not particularly complex, the EM often has insufficient time or does not have the necessary instrumentation:

- By using infrared cameras, weak spots in heat insulation and heat transfer bridges can easily be detected.
- Companies specialising in steam systems can check the functioning of condensate drain-off lines and identify steam leaks.
- Burner settings should be regularly adjusted in order to maintain optimal efficiency and to minimise environmental pollution.
- The integrity of compressed air networks can be checked using various methods.

All these activities must be prepared for in advance with the production manager and carried out methodically. From these activities, the audit reports are gathered together and analysed in detail. If anomalies appear, the team determines who must remedy what and by when. The task of the EM is to regularly meet with the team and to monitor or adapt the progress of the measures being implemented.
4.5 Measures

For any weak points found as a result of data raising and data analysis, potential measures to overcome them must be demonstrated. Varying measures can be ranked according to their costs, the time requirements necessary for integration into the existing structure, cost effectiveness, and logical sequencing of the measures.

4.5.1 Immediate measures

Immediate measures pay for themselves very quickly and can be carried out using the resources on hand.

4.5.2 Mid and long-term measures

These measures are only possible at a considerable investment cost and with advance planning. With regard to the planning of mid and long-term measures to overcome weak points, the sequencing of measures must be carefully looked at. A plan for the execution and integration of these measures must be worked out.

4.5.3 Integration plan

The main requirement of a plan for integrating a measure is to provide a quick overview of the measure and to assist in making decisions simpler for all those participating in the decision making process - such as company management, financial management, production management

4.6 Monitoring

After a measure has been implemented, its success must be measured, compared with the planned outcomes, and regularly checked. In this way manufacturer’s specifications for the installed unit are also checked. If the savings being achieved are below the expected values that were planned for, the reasons for the shortfall need to be investigated.
1 Basic Concept

“Energy is the ability of a system to cause an external effect” (Max Planck)

Thermodynamics is the branch of science that embodies the principles of energy transformation in macroscopic systems. Is not the aim of this program to go deep on thermodynamics study but some concepts like system, surroundings and boundary are important to understand the main concept of energy transfers.

System is taken to be any object, any quantity of matter... selected for study and set apart (mentally) from everything else which is then called surroundings. The imaginary envelope, which encloses the system, is called boundary of the system. A system has an identifiable, reproducible state when all its properties are fixed. Temperature and pressure are examples of properties of a state that can be detected by measuring instruments such as thermometers and pressure gauges.

When a system is displaced from an equilibrium state, it undergoes a process during which its properties change until a new equilibrium state is reached. During a such process the system may be caused to interact with its surroundings so as to interchange energy in the forms of heat and work and so to produce in the system or surroundings changes considered desirable for one reason or another.

Heat - is the energy form crossing the system boundary under the influence of temperature difference or gradient.

Work – is also energy in transit between a system and its surroundings but resulting from the displacement of external force acting on the system.

In real systems the quantity of energy supplied to the system is always greater than the quantity of work and heat together coming from the system. This ratio is called efficiency.
1.1 Units – SI

1.1.1 Base units

<table>
<thead>
<tr>
<th>Metric</th>
<th>S.I. Unit</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Length</td>
<td>1 m</td>
<td>Meter</td>
</tr>
<tr>
<td>Mass</td>
<td>1 kg</td>
<td>Kilogram</td>
</tr>
<tr>
<td>Time</td>
<td>1 s</td>
<td>Second</td>
</tr>
<tr>
<td>Electrical current</td>
<td>1 A</td>
<td>Ampere</td>
</tr>
<tr>
<td>Temperature</td>
<td>1 K</td>
<td>Kelvin</td>
</tr>
<tr>
<td>Material quantity</td>
<td>1 mol</td>
<td>Mol</td>
</tr>
<tr>
<td>Light intensity</td>
<td>1 cd</td>
<td>Candela</td>
</tr>
</tbody>
</table>

1.1.2 Derived

<table>
<thead>
<tr>
<th>Metric</th>
<th>S.I. Unit</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Force</td>
<td>1 N</td>
<td>= 1 kgm/s²</td>
</tr>
<tr>
<td>Energy, work</td>
<td>1 J</td>
<td>= 1 Ws = 1 Nm</td>
</tr>
<tr>
<td>Power</td>
<td>1 W</td>
<td>= 1 J/s = 1 Nm/s</td>
</tr>
<tr>
<td>Pressure</td>
<td>1 Pa</td>
<td>= 1 N/m²</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1 bar = 105000 Pa</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Metric</th>
<th>S.I. Unit</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Specific Heat</td>
<td>1 J/kgK</td>
<td>Capacity</td>
</tr>
<tr>
<td>Spec. Gravity</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>Density</td>
<td>kg/m³</td>
<td></td>
</tr>
<tr>
<td>Thermal conductivity</td>
<td>W/(mK²)</td>
<td></td>
</tr>
<tr>
<td>Heat coefficient</td>
<td>W/(m²K)</td>
<td></td>
</tr>
</tbody>
</table>

1.1.3 SI-prefixes for decimal multiples and fractions

<table>
<thead>
<tr>
<th>Prefix</th>
<th>Abbreviation</th>
<th>Meaning</th>
<th>Prefix</th>
<th>Abbreviation</th>
<th>Meaning</th>
</tr>
</thead>
<tbody>
<tr>
<td>Deca</td>
<td>Da</td>
<td>10¹</td>
<td>Deci</td>
<td>D</td>
<td>10⁻¹</td>
</tr>
<tr>
<td>Hecto</td>
<td>H</td>
<td>10²</td>
<td>Centi</td>
<td>C</td>
<td>10⁻²</td>
</tr>
<tr>
<td>Kilo</td>
<td>K</td>
<td>10³</td>
<td>Milli</td>
<td>M</td>
<td>10⁻³</td>
</tr>
<tr>
<td>Mega</td>
<td>M</td>
<td>10⁶</td>
<td>Micro</td>
<td>M</td>
<td>10⁻⁶</td>
</tr>
<tr>
<td>Giga</td>
<td>G</td>
<td>10⁹</td>
<td>Nano</td>
<td>N</td>
<td>10⁻⁹</td>
</tr>
<tr>
<td>Tera</td>
<td>T</td>
<td>10¹²</td>
<td>Pico</td>
<td>P</td>
<td>10⁻¹²</td>
</tr>
<tr>
<td>Peta</td>
<td>P</td>
<td>10¹⁵</td>
<td>Atto</td>
<td>A</td>
<td>10⁻¹⁵</td>
</tr>
<tr>
<td>Exa</td>
<td>E</td>
<td>10¹⁸</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
1.2 Energy & Power

Energy, Work

Work (W) = Power (P) \times \text{Time (t)}

1 J (Joule) = 1 Ws = 1 Nm

<table>
<thead>
<tr>
<th></th>
<th>J</th>
<th>kJ</th>
<th>kWh</th>
<th>kcal</th>
<th>kpm</th>
<th>tep</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 J</td>
<td>1</td>
<td>0.001</td>
<td>0.278 x 10^{-6}</td>
<td>0.239 x 10^{-3}</td>
<td>0.102</td>
<td>0.024 x 10^{-9}</td>
</tr>
<tr>
<td>1 kJ</td>
<td>1000</td>
<td>1</td>
<td>0.278 x 10^{-3}</td>
<td>0.239</td>
<td>101.97</td>
<td>0.024 x 10^{-6}</td>
</tr>
<tr>
<td>1 kWh</td>
<td>3,6 x 10^6</td>
<td>3600</td>
<td>1</td>
<td>860</td>
<td>367 000</td>
<td>86,0 x 10^{-6}</td>
</tr>
<tr>
<td>1 kcal</td>
<td>4186.8</td>
<td>4.186</td>
<td>0.001163</td>
<td>1</td>
<td>427 000</td>
<td>0.10 x 10^{-6}</td>
</tr>
<tr>
<td>1 kpm</td>
<td>9,981</td>
<td>9,981 x 10^{-3}</td>
<td>2.72 x 10^{-6}</td>
<td>3.7 x 10^{-6}</td>
<td>1</td>
<td>23,43 x 10^{-9}</td>
</tr>
<tr>
<td>1 tep</td>
<td>41,87 x 10^9</td>
<td>41,97 x 10^6</td>
<td>11,63 x 10^3</td>
<td>10,0 x 10^6</td>
<td>4,26 x 10^9</td>
<td>1</td>
</tr>
</tbody>
</table>

Power

Power (P) = \frac{\text{Work (W)}}{\text{Time (t)}}

1 W (Watt) = 1 J/s = 1 Nm/s

<table>
<thead>
<tr>
<th></th>
<th>W</th>
<th>kW</th>
<th>kcal/h</th>
<th>kpm/s</th>
<th>PS</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 W</td>
<td>1</td>
<td>0.001</td>
<td>0.860</td>
<td>0.102</td>
<td>0.00136</td>
</tr>
<tr>
<td>1 kW</td>
<td>1000</td>
<td>1</td>
<td>860</td>
<td>102</td>
<td>1.35778</td>
</tr>
<tr>
<td>1 kcal/h</td>
<td>1.1628</td>
<td>0.0011628</td>
<td>1</td>
<td>0.119</td>
<td>0.00158</td>
</tr>
<tr>
<td>1 kpm/s</td>
<td>9.80665</td>
<td>0.0098067</td>
<td>8.43</td>
<td>1</td>
<td>0.01333</td>
</tr>
<tr>
<td>1 PS</td>
<td>736.498</td>
<td>0.7365498</td>
<td>632</td>
<td>75</td>
<td>1</td>
</tr>
</tbody>
</table>

(tep – equivalent petroleum tonne is listed as energy unit once portuguese energy legislation refers specific energy consumption in tep or kgep.

kpm – kilopond

PS – metric horse power)
1.2.1 Calculation example

For most physical constants, work is stated in kJ. However, for technical calculations work can be expressed, for example, in kWh.

Example:

1. Specific Heat capacity \( C_{\text{Water}} = 4.184 \text{ kJ/kg ºK} \)
   The conversion from kJ into kWh is arrived at as follows:
   
   \[
   1 \text{kJ} = 1 \text{kWs} = 1 \text{kWs} \times 1\text{h}/3600\text{s} = 1/3600 \text{kWh}
   \]

   Therefore Heat capacity \( C_{\text{Water}} \) in kWh:
   
   \[
   C_{\text{Water}} = 4.184 \text{ kJ/kg Kº} = 4.184 / 3600 \text{kWh/kg Kº} = 1.1616 \times 10^{-3} \text{kWh/kg Kº} \text{ or 1.16Wh/kg Kº}
   \]

2. Specific Heat capacity \( C_{\text{air}} = 1.005 \text{ kJ/kg ºK} \)
   The conversion from kJ into kWh is arrived at as follows:
   
   \[
   1 \text{kJ} = 1 \text{kWs} = 1 \text{kWs} \times 1\text{h}/3600\text{s} = 1/3600 \text{kWh}
   \]

   Therefore Heat capacity \( C_{\text{air}} \) kWh:
   
   \[
   C_{\text{air}} = 1.005 \text{ kJ/kg Kº} = 1.005 / 3600 \text{kWh/kg Kº} = 0.28 \times 10^{-3} \text{kWh/kg Kº}
   \]

1.3 Forms of Energy:

Two kinds of energy are kinetic and potential. Kinetic energy is the energy of motion. Potential energy is stored energy.

Energy is available in various forms:

- Mechanical energy
- Thermal energy
- Chemical bound energy
- Physical bound energy
- Electromagnetic radiation energy
- Electrical energy

1.4 Energy Levels

All these forms of energy can be broken down either into kinetic or potential. Law of Conservation of Energy- Energy can neither be created nor destroyed. Energy is always changing from one kind to another. The total energy of an object never changes.
Potential energy + Kinetic energy = Total energy and
Total energy - Kinetic energy = Potential energy and
Total energy - Potential energy = Kinetic energy

Figure 1-2 Examples of potential that follow from non-equilibrium distributions of energy. Whenever energy (in whatever form) is out of equilibrium with its surroundings, a potential exists for producing change that, following the second law of Thermodynamics is spontaneously minimized.

Energy level: The same forms of energy can occur at different levels. An example is heat that can be perceived as being either cold or hot, depending upon the level.

Energy flow: If two different energy levels of the same kind of energy are present an energy flow from the higher to the lower level takes place caused by the tension or gradient between them. The transfer phenomena will continue until equilibrium is achieved. The transfer ratio depends on the physical and geometrical characteristics of the media through which energy flow occurs.

Energy flow = gradient / resistance
According to the level of transformation before last usage form, energy can also be classified as:

**Primary energy**: Energy that has not been subjected to any transformation in other form of energy:
E.g. water power, chemical energy in crude oil, natural gas, coal, wood, mechanical energy of the wind, radiant energy of the sun’s radiation, ...

**Secondary energy**: Energy after the first transformation from raw form:
E.g. electricity after conversion in hydro-power stations, wind power stations, steam power stations or atomic power stations, petrol from the refinery, LPG from crude oil,...

**Useful or net energy**: Energy of a type used or utilized by the end consumer:
e.g. warmth, cold, force, pressure, light, sound, movement, ...;
*Useful energy is energy after the last transformation.*

**Energy service**: That which one obtains from the use of energy:
e.g.. a clean shirt after washing, mobility, entertainment, lighting, a pleasant temperature in the work area, ...;

Note that the same type of energy can be used in different forms, for example, wind energy can be used directly in a wind mill or indirectly if the mill is driven by an electrical motor using electrical energy produced by a wind generator.
Is a question of to have the suitable kind of energy available were the utilization is needed.

### 1.5 Ideal Gas Law

It is well known that compressing a gas increase its pressure and warming a gas increase its volume.

![Ideal Gas Law Diagram]

*Figure 1-4*

The opposite is also true.

These pressure and volume changes do not happens evenly, they happen according to a physical low known as **Ideal Gas Law**.
Energy Fundamentals
Preparation material
www.european-energymanager.net

\[ PV = RnT \]

Where:
P – pressure (bar)
V – volume (m\(^3\))
T – absolute temperature \(^{\circ}K\)
R – perfect gases constant (=8.1334 J mol\(^{-1}\) \(^{\circ}K\)^{-1})
n - number of moles

Applied to the same quantity of the same gas the variation of one of them can be computed once we know initial conditions for all and final conditions of the other two

\[ V_c = V_m \times \frac{P_m}{P_r} \times \frac{T_r}{T_m} \]

Where:
\( V_c \) – gas volume at normal conditions, i.e. reference conditions (Nm\(^3\))
\( V_m \) – gas volume at working conditions (m\(^3\))
\( P_m \) – working pressure (bar)
\( P_r \) – reference or normal pressure 1.033 bar
\( T_m \) – working absolute temperature 273\(^{\circ} K\)+T\(^{\circ} C\))
\( T_r \) – reference temperature = 273\(^{\circ} K\)

This theoretical principle is very important to evaluate accurately the quantity of energy of a gaseous fuel like natural gas or propane. The quantity of energy is related with quantity of mass, not volume, and the volume of a certain quantity of gas, as stated before, depends on the pressure and temperature conditions. Energy manager must be aware about this to become sure that the volumes of the gaseous fuels considered in his calculations are properly corrected to normal conditions.
1.6 Energy Sources

Practically every substance and every body can be a source of energy in forms such as heat, light, movement, chemically bound, atomic or potential energy.

<table>
<thead>
<tr>
<th>Fuel</th>
<th>Heat value</th>
<th>Calorific value</th>
<th>Max. CO2 emission (kg/kWh) as related to the:</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>PCI</td>
<td>PCS</td>
<td>Heat value</td>
</tr>
<tr>
<td>Bituminous coal</td>
<td>8.14 kWh/kg</td>
<td>8.41 kWh/kg</td>
<td>0.350</td>
</tr>
<tr>
<td>Coke</td>
<td>7.50 kWh/kg</td>
<td>7.53 kWh/kg</td>
<td>0.420</td>
</tr>
<tr>
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<td>0.410</td>
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<tr>
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<tr>
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<td>0.312</td>
</tr>
<tr>
<td>Heating oil S</td>
<td>10.61 kWh/l</td>
<td>11.27 kWh/l</td>
<td>0.290</td>
</tr>
<tr>
<td>Natural gas L</td>
<td>8.87 kWh/Nm3</td>
<td>9.76 kWh/Nm3</td>
<td>0.200</td>
</tr>
<tr>
<td>Natural gas H</td>
<td>10.42 kWh/Nm3</td>
<td>11.42 kWh/Nm3</td>
<td>0.200</td>
</tr>
<tr>
<td>Town gas</td>
<td>4.48 kWh/Nm3</td>
<td>5.00 kWh/Nm3</td>
<td>0.200</td>
</tr>
</tbody>
</table>

The calorific value of a fuel is the quantity of heat produced by its combustion, at constant pressure and under the conditions known as "normal" of temperature and pressure (i.e. to 0°C and under a pressure of 1.013 bar). The combustion of hydrocarbons generates water vapour. Certain techniques make it possible to recover the quantity of heat contained in this water of combustion by condensing it (e.g. condensing boilers)

One thus distinguishes two calorific values:
The lower calorific value or Net calorific value (NCV) which supposes that the products of combustion contain the water of combustion to the vapor state. The heat contained in this water is not recovered.
The higher calorific value or Gross calorific value (GCV) which supposes that the water of combustion is entirely condensed. The heat contained in this water is recovered.

PCI : lower calorific value of gas. PCS : Gross calorific value
2 Optimizing strategies

Optimising the energy utilization means to organize a system that can ensure that the energy is used with best possible efficiency.

The most significant forms of energy used in industry are fuels and electricity.

2.1 Fuels

Fuels (natural gas, propane, gas oil and fuel oil) are mainly used in combustion processes in boilers and dryers. To minimise losses and increase efficiency is necessary to guarantee:

- Control the combustion conditions
- Good insulation of production and distribution equipment and pipes.

2.2 Electricity

Electricity’s main applications are power, cold and light. In the electrical drives module, optimisations aspects of electrical power was already considered, regarding cold and light, some strategies should also be taken to ensure the best utilization efficiency.

Freezing chambers
- Insulation, proper design and good maintenance;
- Optimising the utilisation.

Light
- More efficient lamps and lamps housing
- Automatic on and off switch.

3 Measurement and regulation

The objective of regulation is optimising the control equipment work that composes a process to the own process necessities. The majority of the processes are sensible to internal and external variations so the control equipment must response in the better and quick possible way in order to prevent out of control situations. In control systems there are two types of variables, the process variable (PV) and the control variable (CV).

3.1 Measurement equipment

For temperature measurement it is possible to use a thermocouple or a infrared radiation pyrometer. The choice of what kind of equipment should be done depends on application and the temperature range.
For pressure measurement it could be used simply pressure manometer or a pressure transmitter.

For mass measurement electronic or analogue scales are used.

Flow measurement: Liquid flow and gas flow measurements.
The former one could be done using various measuring principles, like electromagnetic, coriolis, ultrasonic, vortex, differential pressure flow or mechanical turbine flow meter. The right choice as to do with the application requirements and depends on the conductivity of the liquid and its viscosity. The last depends of gas type, if it is clean or dirty, and could be done with the coriolis, Vortex, thermal or differential pressure flow principles.

3.2 Regulation system
The regulation systems must have the capacity of controlling the process variable even when unexpected variations occur.

Variable speed drives are one of the best examples of regulation system. This equipment has the capacity of control de velocity, current, torque of a electrical motor. It can be used to control a gas or liquid flow through a pipe when is applied to a fan or a pump. It can control the linear speed of a rubber conveyer by controlling angular speed of the electrical motor. It can control the depression inside a smelter adjusting the rotation speed of the draught fan. Another type of flow regulator is the damper. This equipment could be controlled manually or by a servomotor. Other examples are Multi speed motors, Pulse width modulation inverter

3.3 Controllers
Controllers are designed to eliminate the need for continuous operator attention. The set-point is where you would like the measurement to be. Controller receives the measurement and sends the error signal, which is the difference between set-point and measurement to the regulator in order to modify the process variable.

All these types of regulation could be used for stand alone controllers or centralise into a system that supervisor all the variables in a process. This kind of approach is called CIM (Computer integrated Manufacturing). The computer receives all the information through network linking programmable logic controllers (PLC) or/and others controllers. This information could be saved in databases to keep a historical for the process.

Different types of controller:

- Proportional controllers – pure gain or attenuation
- Integral controllers – integrate error
- Derivative controllers – differentiate error
P controller: termed proportional because output is not exactly linear in relation to input current. Despite their nonlinear response, an inexpensive way to control position, velocity, or force on equipment requiring high-speed response at high flow rates. The purpose of P controller is to decrease the steady-state error, but it has the side effect, that is, larger overshoot and could give rise to the oscillation.

I controller or Integral controller: The purpose of I controller is to eliminate the steady-state error, since it increases one pole in origin.

The D controller is used to increase the stability, but it increases the noise in high frequency.

PID stands for Proportional, Integral, Derivative.

The variable being adjusted is called the manipulated variable which usually is equal to the output of the controller. The output of PID controllers will change in response to a change in measurement or set-point. Manufacturers of PID controllers use different names to identify the three modes.

**System Control And Data Acquisition** (SCADA) A process control application that collects data from sensors in remote locations and sends them to a central computer for management and control.

**Direct Digital Control system (DDC):** Use of digital computer to perform required automatic control operations in a total energy management system.

**Programmable Logic Controller (PLC):** These computers replace relay logic and usually have PID controllers built into them. PLCs are very fast at processing discrete signals (like a switch condition).
Energy requirements of buildings /energy efficient buildings

Preparation Material

Introduction

Internal conditions in buildings require governing and control to take account of the needs of the structure and the personnel working within. Any building, whilst being an inert structure, will react to the influence of climate and the interactions of the users of the premises. Whilst the building structure, and the people inside, must be protected from the extremes that nature can thrust upon them stable conditions must be maintained to allow the carrying out of the activities for which the building has been created. This has to be done using sound construction approaches plus the efficient application of energy consuming plant.

To function efficiently all aspects of the building’s design and equipment need to be matched carefully to projected requirements. Because, in the past, the use of energy in buildings has not been particularly well regulated changes are now taking place which are beginning to specify the quality of materials, the building orientation, levels of Insulation, and the efficiency of installed equipment to provide basic heating, cooling, ventilation and lighting. Similarly the provision of both hot and cold water services must also be specified based on occupancy requirements and energy demands. Ventilation and temperature control must be such that air volumes are exchanged at certain rates to remove smells, moisture, and other contaminants otherwise the atmosphere becomes foul, dangerous or condensation can take place. The absorption of moisture by the internal building fabric, if the temperature falls below a certain temperature (dew point), will lead to the deposition of liquids which will promote the breakdown of internal surfaces and the growth of fungi. Such poor maintenance of the air in a building can result in the occurrence of so called ‘sick building syndrome’ which leads to people working within the property suffering from adverse health conditions. Where chemicals are used that give off fumes ventilation must be sufficient to keep the levels below danger levels whilst, at the same time, minimising the loss of space heat.
Current formalised building regulations can be found in documents such as the UK Building Regulations Parts L1 and L2 and the EU document COM(2001) 226 – Directive of the European Parliament and of the Council on the energy performance of buildings. These now state mandatory aspects of building design and construction that take into account the environmentally influencing features of materials used and energy consumed inside the building.

Principally the Designer and Energy Manager should be aware of the variance in heating demands brought about by annual climate variations which place demand on installed heating and cooling plant. Similarly the sizing and positioning of windows and other apertures will influence ventilation, natural light availability and solar thermal gain.

The graph demonstrates the conditions that prevail in the UK where the hours below freezing are relatively low (<7%) and the time above an external temperature norm of 16 degrees C is larger (20%). Once the ambient temperature rises above 16 degrees C it is normal to consider switching off heating systems and appliances however it is human nature to use heat providing resources to a higher level – sometimes to the point where the heating conflicts with the cooling plant installed, especially if thermostats have been adjusted incorrectly.
Such a graph indicates that, in one EU state, periods of intense cold or higher temperatures are relatively small and so heating and cooling plant needs to be sized accordingly. Heating and Cooling plant that is capable of dealing with an Artic or Sahara like temperatures is not required in this location. Levels of insulation, structure air gaps and multiple glazing components are dependant on the predicted extremes.

Using the historical data, available at certain locations from metrological institutions, it is possible to plot a graph of actual temperature variations around a baseline condition using data called ‘Degree Days’. Amongst various analytical tools this course will look at Degree Days as they allow energy managers too compare their heating and cooling load variations with the actual climate prevailing. Such comparisons will indicate over consumption and how closely and effectively heating systems are controlled plus highlight occasions when thermostats and other controls fail or are incorrectly adjusted.

The main issue of concern for those responsible for a building’s energy consumption is the thermal conductivity of the structure. It is well understood that if the air temperature reduces a natural human reaction is to retain heat by adding more clothing. When we are not protected by a building we can go to considerable lengths to add clothing to produce an adequate insulation level that stops our bodies from losing heat to the colder environment. A building cannot add and remove insulation as required due to seasonal changes. It must be constructed to take into account the average conditions likely to prevail and those materials and conditions which minimise the need for internal heating and ventilation.

Unfortunately there is a point where a balance has to be reached. Too much insulation and the building would get hotter and hotter due to the accumulation of heat through the equipment used inside and the people working there; every computer and every person is a heat emitter. If there is
too little insulation the level of heat loss, when the outside temperature is low, would be so great that outdoor clothing has to be worn indoors. Insulation has to be designed to meet the particular demands of the application of the building. High levels of insulation are essential for refrigerated process areas such as food handling units, as the aim is to keep the produce chilled or frozen whatever the external temperature. Similarly high levels of insulation are required for premises such as hospitals where the occupiers are sick or infirm and therefore less likely to be active and producing sufficient body heat.

Whatever the application simple calculations allow the designer and energy manager to arrive at a perception of the different levels of insulation effectiveness of different materials and combinations.

The movement of thermal energy is known as thermal transmittance (the U value) and is a measure of how much heat will pass through 1m$^2$ of a structure when the air temperature on either side varies by one degree C. U values are given in watts per meter squared per degree change ($W/m^2K$). As an example a 105mm solid brick wall unplastered has a U value of 3.3 however increasing the brickwork to a thickness of 335 mm reduces the U value to 1.7 thereby virtually halving the potential heat loss. This can be improved upon by using two layers of brick with an air gap between them which is then filled with insulating material. The 1.7 now reduces to 0.5; however this is at the cost of more expensive construction techniques and additional insulating materials. However a reduction in heat loss of 85% will reduce demand on fitted heating systems in terms of their installed capacity and actual energy consumed.
Current UK building regulations specify that all buildings should have minimum insulation standards as shown below.

In the UK it is interesting to note that account is taken of the fact that conditions vary depending on location. For instance England and Wales (E & W) are allowed 0.35 as the heat loss for external walls yet in Scotland this is more stringent at 0.3 as a recognition of the colder winters in the North.

Later in the module we will look at simple auditing practices using an Excel spreadsheet which allows the engineer to size heating systems effectively by calculating the total heat loss for a property. Similar approaches are available for calculating lighting levels and installed electrical capacity. Later we will provide a complete auditing tool which will allow the engineer to record the use of energy in specific spaces using simple judgemental criteria and arrive at the actual running cost for each individual location taking into account installed equipment, working patterns and costs of energy supplies.

**Domestic Hot Water**

There are also simple rules about the supply of hot water for domestic applications in toilets, kitchens, canteens and other areas. Recently there has been a trend away from a centralised hot water plant because the storage vessel has to be well insulated as does the transmission pipe work from the
heat exchanger to the point of use. Such pipe work can have long lengths of pipe which increases the opportunity for loss. Typically in a hot water circulated system hot water must arrive at the tap at +50 degrees C within 1 minute of opening the tap, and water must be heated to at least 60 degrees C at the point of initial heating and storage. All of this is to limit the development of lethal legionella bacteria in the system. The modern approach is for low volume supplies to be met by direct heaters at the point of use i.e. over the sink to reduce the risk and also the energy load.

Again using simple heating calculations and estimates of the quantity of hot water required at any time at any location it is a practical exercise to limit the energy consumed by careful choice of system, insulation and location.

As suggested earlier the third standard resource in any building is the lighting. Whatever the activity some artificial lighting will be required to supplement daylight even if it is just for night time usage. It would be simple to employ large windows which permitted lots of daylight to enter but as we know, from the garden, a greenhouse will get hotter and hotter because of trapped heat in the summer and yet very cold in the winter. Glazing is not an effective insulator with a U value of 6.6 for roof lights, 5.6 for single glazed metal framed windows and 2.0 for good quality triple glazing. Therefore there has to be a balance between the amount of windows and the amount of more substantial brickwork or structure. In the UK windows are now limited to a maximum of 25% of the wall / roof surface of a building with further consideration being given to which way the windows face to take account of summer and winter sun positions.

Artificial lighting itself raises issues of what type of fitting is best for the application. There are a wide range of different light emitters which have to be evaluated in a number of ways to make sure that they meet the specific needs of the occupiers and any activities. Lighting is covered in detail in another module.
Correct lighting is therefore a prime building efficiency issue with choices made at the time of construction which can affect the overall running costs of that building. Similarly the installing of the cheapest heating units, or windows or wall / roof construction will look cost effective until the long term impact of the running costs is assessed.

The approach to energy efficient buildings is therefore to consider them as a complete entity with both construction and installed equipment taken into account to allow a mapping of the overall environmental and cost impact of the premises.

To pursue this module we recommend that candidates evaluate the following areas so that they understand the implications of choices made in the construction and operation of buildings.

- Any national building regulations that currently apply
- EU building regulations
- National Climate patterns
- Types of building materials currently in use plus U values
- Current approaches to heating, cooling and ventilation of premises
- Types of light fittings available and their ratings
- Any other National rules and regulations pertaining to water and energy use.
Preparation Material

Introduction

Internal conditions in buildings require governing and control to take account of the needs of the structure and the personnel working within. Any building, which contains personnel, whatever their activities and duties, will either need heating or cooling.

The Designer and Energy Manager should be aware of the variance in heating demands brought about by annual climate variations which place demand on installed heating and cooling plant.

Variations in UK outdoor temperatures

The graph demonstrates the conditions that prevail in the UK where the hours below freezing are relatively low (<7%) and the time above an external temperature norm of 16 degrees C is larger (20%). Once the ambient temperature rises above 16 degrees C it is normal to consider switching off heating systems and appliances however it is human nature to use heat providing resources to a higher level – sometimes to the point where the heating conflicts with the cooling plant installed, especially if thermostats have been adjusted incorrectly.
Heat Transfer

Heating, whether supplied artificially or by nature, reaches the user in one of three ways: Convection, Conduction and Radiation. All three types of transfer, when produced by heating equipment are very effective but sometimes use completely different methodologies dependent on the application. Quite often the heating of a space can employ all three approaches.

Conduction

Conduction is where thermal energy (heat) is transferred through a solid material partially as a result of molecular collision as a result of the flow of electrons which is induced by a temperature differential. Usually the denser the material the better is its ability to conduct heat. Less dense materials such as gases are not conductors. This is why metals are a good conductor of heat. In a boiler the heat from the combustion of fuel is contained in metal tubes surrounded by water. Because they are made of metal quick heat transfer takes place across the tube wall by conduction to heat up the water.

Convection

Convection current heat transfer is caused by fluid movement and the difference in density in that material. If heated air or liquid rises it is said to be experiencing Natural Convection. If a fan or pump is used to accentuate or even create the flow then that is known as Forced Convection.

Natural convection is experienced when heat rises in the air from heaters or heat sources and creates stratification where the higher levels are warmer than the lower. Eventually the heated air will cool and start to drop whilst warm air rises to replace it – this loop is known as a convection current and is best demonstrated when watching a glider as it rises on ‘thermals’ (ground heated air) to greater heights.
Radiation

The final mode of heat transfer is by Radiation which is present in the form of electromagnetic waves and is in contrast to convection and conduction as it requires no medium. The heat felt from an open fire or from the Sun, 150 million kilometres away, is radiated energy.

All heating systems, whether industrial, commercial or domestic, use one of these approaches or sometimes a combination of all three. A domestic or office central heating radiator is a perfect example in that water is heated in a boiler and circulated to the unit. The heat from the hot water conducts through the metal body to the outside where it radiates heat to the surrounding air which rises and circulates around the space by conduction.

Heating equipment

Heating can be supplied to spaces either by the direct combustion of fuel or by using secondary mediums such as steam, thermal fluid or electricity.

Primary heating from fossil fuels and other combustibles can be provided by an open fire or under control through gas fired ceramic plaque heaters.

These principally rely on radiated heat from the combustion surface.
Secondary heating can come from some of the following sources:

- Hot water circulating through pipes or emitters such as radiators sometimes with fan assistance to blow cold air across the heated surface (as in Air Handling units)
- Steam or thermal fluid circulating through pipe work and other heat exchangers
- Electricity heating resistance wire which generates rising warm air currents sometimes with fan assistance
- Electrically heated oil filled panels which act like hot water radiators
- Electric radiant plaques – Infra red heaters
- Radiant tubes where gas is combusted inside and heat radiates from the black outer surface of the tube

**Convective heating systems**

![High-level unit heater](image)

![Floor standing warm air heater](image)

![Ducted warm air system](image)

![Warm air jet/Induced jet system](image)
Each method has advantages and disadvantages.

Using convection and heated air approaches in a factory or large space needs some time to elapse before the whole volume of the air is heated to the specified level. On a cold winter morning this will necessitate pre heating for some time. Thermostatic control is achieved by monitoring the space air temperature at a strategic location. The system is effective at maintaining air temperatures as long as no large volumes of outside air are allowed to enter
to chill the heated volume. If cold air does enter then it dilutes the heating effect and more energy must be consumed to reheat the space. This is a typical problem in an office when someone opens a window because it is too warm or else a factory roller shutter door is opened to allow vehicular access.

Pure radiant heating has some considerable advantages in that the heaters only heat the people and the objects that the emitter is aimed at. Space heating using radiant heaters can be turned on shortly before occupancy and will immediately give the impression of warmth similar to that perceived from the sun or an open fire. The operation of the heaters cannot be managed with air sensing thermostats as the rise in air temperature only comes from infra red heat being absorbed by people, machines, equipment and the building material being radiated back into the space. Radiant heat thermostats are usually matt black coloured sensors, mounted at shoulder level which sense the radiant energy being produced and absorbed.

Heating Efficiency
The efficiency or effectiveness of any heating installation will depend on a number of aspects of the heat generation and its application. In primary heating the direct combustion will produce radiant heat and create a degree of warmed air however some thermal energy will be lost in the exhausting of combustion products to atmosphere.

In secondary heating methods the conversion to thermal energy is managed in the heat exchanger, for instance a boiler, where the combustion is tuned to the conversion process so that the outcome product – hot water, steam or thermal fluid - is as absorbent as possible of all the energy in the original fuel. A modern condensing boiler will abstract over 90% of the energy initially present in the gas or oil fuel that has been combusted. That heat can then be transferred via insulated pipe work to where it is required for application.
Older boiler plant used to less efficient with a conversion efficiency of between 75 and 80% so over 1/5th of the energy present was lost in the conversion process. If the plant is not well maintained then that conversion efficiency can fall further to the point where half of the energy in the fuel is wasted which means twice as much will be required to heat the space.

Heating systems can become extremely expensive to run when the fuel conversion is not efficient or the heat is lost because of open doors and windows. Insulation of distribution systems is also essential as long pipe runs carrying hot liquids can cool them before they ever reach the point of use.

It is therefore critical that the design of the heating installation considers a number of factors:

- Where is the heat required?
- What is the coldest likely situation for which heat is needed?
- What fuels are available?
- Can we use solar energy?
- Would heat pumps be effective?
- Will we use primary or secondary processes?
- Will we heat the air or use radiant systems?
- What level of control is required?
- How will the heat be distributed?
- Can the heating system be zoned so that we don’t heat empty spaces?
- Are there likely to be any conflicts with Air Conditioning systems?
- What maintenance is required to maintain efficient operations?
- How do we monitor heating effectiveness?
- What are degree days?

These and many other associated points and questions will be discussed and clarified in the practical part of this module.
If one observes a production process many energy flows which influence each other to some extent are visible. Even though the following lesson mainly relates to process heat, the systematics can also be applied to other energy sources.

**Parameters that influence the energy requirement**

The energy requirement for process heat depends on:

- The temperature selected as well as, if applicable, the pressure selected
- The optimal degree of efficiency with regard to heat production
- The minimisation of losses (radiation, standby, exhaust gas and distribution losses)
- Regulation (running time and temperature)
- System optimisation
- Electricity consumption by support systems
Efficiency $\eta$

<table>
<thead>
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<th></th>
<th>Ideal</th>
<th>Real</th>
</tr>
</thead>
<tbody>
<tr>
<td>Production</td>
<td>99%</td>
<td>75%</td>
</tr>
<tr>
<td>Distribution</td>
<td>99%</td>
<td>90%</td>
</tr>
<tr>
<td>User</td>
<td>99%</td>
<td>50%</td>
</tr>
<tr>
<td>Total</td>
<td>97.0%</td>
<td>33.8%</td>
</tr>
</tbody>
</table>

$\eta$ = minimum requirement/consumption

$\eta = \frac{\text{Utilisable heat } Q_N}{\text{Fuel } Q_B}$

$\eta = Q_N \text{ out } / Q_N \text{ in}$

Hot air, warm or hot water and steam (as vapourised water) or thermal oil, as well as many other materials, are used as heat carriers for the transfer of energy in operational processes. For the implementation of optimisation measures, the following steps should be followed:

1. **Avoidance** of unnecessary energy consumption
2. **Efficient energy utilisation** in existing units
3. Introduce **new technologies / units**

In this regard, particular potential exists in the optimisation and automation of processes along with an appropriate training programme for the plant personnel. In this way losses caused by a careless approach to heat can be avoided (e.g. switching off the heat flow during idle time or production breaks). Large savings potentials can be achieved with minimal financial inputs through purely organisational measures (e.g. bringing plant into service on a phased time bases - in the case where several heat consuming units exist). Opportunities for recovering heat should always be watched out for. This is especially relevant with regard to planned investment into new heat producing or consuming units where the costs of heat recovery can often be amortised over a short period of time.
Fuel Characteristics

In the case of conventional heat production, one uses chemically bound energy from the energy source being used (oil, gas, coal, wood) that generally exists in the form of carbohydrates (CnHm). Combustion converts these into carbon dioxide - CO2 - and water - H2O.

If water escapes in the form of steam, one talks in terms of the lower calorific value Hu. If, however, heat is accounted for in terms of release due to the condensation of existing water vapour, one obtains the upper calorific or combustion value.

The efficiency of energy production units is normally related to the lower calorific value - which does not take into account the heat of condensation. Because of this, lower calorific value measuring devices often show efficiency levels of over 100%. When related to the upper calorific value, the efficiency level naturally lies below 100%.

The upper calorific value generally depends on the amount of hydrogen bound within the fuel being considered. The higher the proportion of hydrogen, the greater the relationship between the upper to the lower calorific value and the greater the additional energy yield achieved by the calorific value technology.

<table>
<thead>
<tr>
<th>Fuel</th>
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<td>7.53 kWh/kg</td>
<td>0.420</td>
<td>0.418</td>
</tr>
<tr>
<td>Brown coal (raw)</td>
<td>2.68 kWh/kg</td>
<td>3.20 kWh/kg</td>
<td>0.410</td>
<td>0.343</td>
</tr>
<tr>
<td>Brown coal- briquettes</td>
<td>5.35 kWh/kg</td>
<td>5.75 kWh/kg</td>
<td>0.380</td>
<td>0.354</td>
</tr>
<tr>
<td>Heating oil EL</td>
<td>10.08 kWh/l</td>
<td>10.57 kWh/l</td>
<td>0.312</td>
<td>0.298</td>
</tr>
<tr>
<td>Heating oil S</td>
<td>10.61 kWh/l</td>
<td>11.27 kWh/l</td>
<td>0.290</td>
<td>0.273</td>
</tr>
<tr>
<td>Natural gas L</td>
<td>8.87 kWh/mn3</td>
<td>9.76 kWh/mn3</td>
<td>0.200</td>
<td>0.182</td>
</tr>
<tr>
<td>Natural gas H</td>
<td>10.42 kWh/mn3</td>
<td>11.42 kWh/mn3</td>
<td>0.200</td>
<td>0.182</td>
</tr>
<tr>
<td>City gas</td>
<td>4.48 kWh/mn3</td>
<td>5.00 kWh/mn3</td>
<td>0.200</td>
<td>0.179</td>
</tr>
</tbody>
</table>

In the case of fuels that are not classified as standard fuels (waste and residues), the calorific value depends upon the material characteristics and the water content. The requirements for combustion are standardised by means of the BImSchV.
Heat recovery from process waste heat

In order to be able to implement heat recovery, the level of the waste heat must be useful, i.e. higher than the intended use temperature, otherwise heat pumps (vapour condensors) must be used.

<table>
<thead>
<tr>
<th>Use area</th>
<th>Temperature</th>
<th>Medium</th>
</tr>
</thead>
<tbody>
<tr>
<td>High Temperature HT</td>
<td>&gt;200°C</td>
<td>Ceramics/steel</td>
</tr>
<tr>
<td>Roasting</td>
<td>200°C</td>
<td>Exhaust gas</td>
</tr>
<tr>
<td>Medium Temperature MT</td>
<td>&gt;100°C</td>
<td>Food processing</td>
</tr>
<tr>
<td>Extraction (e.g. soya oil)</td>
<td>&lt;160°C</td>
<td>Steam/heating water/thermal oil</td>
</tr>
<tr>
<td>Low Temperature LT</td>
<td>&lt;100°C</td>
<td>Washing</td>
</tr>
<tr>
<td>Galvanic baths</td>
<td>&lt;60°C</td>
<td>Hot water</td>
</tr>
<tr>
<td>Photo film development</td>
<td>&lt;40°C</td>
<td>Hot water</td>
</tr>
<tr>
<td>Drying</td>
<td></td>
<td>Hot air</td>
</tr>
</tbody>
</table>

Heat recovery, waste heat utilisation and the use of heat pumps are highly recommended from the overall energy use perspective. Up to ten times more heat can be recovered with these technologies compared to using electricity. In this regard, the matching of the quality and the (timeliness of) availability with the needs of heat consuming units is a prerequisite. Different ways exist for providing solutions, each one according to the production specific constraints and the quality of the heat source as well as the needs of the consumption unit. As a rule, heat exchangers have the least electricity requirements. For example, the heat from the exhaust air arising from ventilation and air conditioning units can be recovered in the most economic way using these. Therefore this technology should be used in most units today.
The integration of combined cycle systems and heat pumps is possible without directly interfering in the process area.

Utilisable waste heat accumulates in association with a diverse range of industrial machines and processes:

- Motors und machines
- Compression for cooling and refrigeration processes
- Ventilation
- Waste water
- Drying processes
- Production units and finishing processes
- Exhaust gas from combustion processes
- Vapourisation from steam supply systems

In addition to directly feeding back into the process, other use areas include:

- Water heating
- Room heating
- Pre-warming
- Cold recovery
- Drying
- Feeding into the heating network.
Combined heat and power
Selecting, installing & operating CHP

Introduction

Combined Heat and Power (CHP) involves generating electricity on-site and utilising the heat that is a by-product of the generation process.

CHP can offer an economical method of providing heat and power which is less environmentally harmful than conventional methods.

Where applicable, building designers, specifiers and operators should always consider the option of CHP as an alternative means of supplying energy.

Where possible, heat and power demands should be linked together through heat networks to form more significant energy demands that benefit from larger CHP e.g. community heating. If this is not possible, then consider supplying individual buildings using CHP.

A brief option appraisal should always be carried out when replacing major plant or designing new systems to identify if CHP might be viable. If CHP begins to look like a leading option then a full feasibility study will need to be carried out.

Overall energy costs can be reduced

Electricity from traditional sources is a relatively high cost, high emission energy due to distribution losses and the poor efficiency of most power stations. Local CHP will generally achieve savings on electricity costs that should more than offset the increase in fossil fuel (usually gas) requirements and maintenance costs.

Environmental improvements

Each kWh of electricity supplied from the average fossil fuel power station results in the emission of over half a kg of CO\textsubscript{2} into the atmosphere. Typically, gas-fired boilers emit around one quarter of a kg of CO\textsubscript{2} per unit of heat generated. CHP has a lower carbon intensity of heat and power production than these separate sources and this can result in more than a 30% reduction in emissions of CO\textsubscript{2}, thus helping to reduce the risk of global warming. It will also reduce the emission of SO\textsubscript{2}, the major contributor to acid rain and help to conserve the world's finite energy resources. The environmental benefits can be clearly seen in the figures below.
Increased security of power supply

The CHP plant can be configured to continue to supply power should the grid fail, and conversely the local electricity network can provide power when the CHP plant is out of operation.

What is CHP?

Combined heat and power is the generation of thermal and electrical energy in a single process. In this way, optimum use can be made of the energy available from the fuel.

CHP installations can convert between 70% to 90% of the energy in the fuel into electrical power and useful heat. This compares very favourably with conventional power generation which has a delivered energy efficiency of around 30-45%.

CHP installations can run on natural gas, bio-gas or diesel (gas oil). Reliability of CHP is generally good with availability factors of over 90% being common. The energy balance of a typical CHP plant is shown below.

The high efficiencies achieved are much greater than conventional power stations, reducing the amount of primary energy required to satisfy a given heat and electrical load. Site energy cost can be reduced significantly using CHP. The
delivered energy consumed on a site will increase due to CHP but overall primary energy consumption and CO₂ emissions will decrease. As a rule of thumb, CHP plant must operate for about 5,000 hours per year or about 14–16 hours/day to be economic, although this depends on the application. Usually, shorter paybacks, e.g. around 5 years, can only be achieved where there is a significant year round demand for heating and hot water, e.g. in hospitals, hotels or swimming pools.

**Small scale CHP** - is most commonly retrofitted to existing building installations although CHP can prove to be even more beneficial in new buildings. Small-scale plant has electrical outputs of up to about 2 MWₑ, and usually comes as packaged plant, often based on gas-fired reciprocating engines, with all components assembled ready for connection to a building's central heating and electrical distribution systems. Small gas turbines and micro-turbines are now also available within this size band.

**Large scale CHP** – generally above about 2 MWₑ, is designed specifically for each application. Larger multi-building installations (e.g. hospitals, universities), industrial sites and community heating use either gas turbines or large reciprocating engines, fuelled by gas or oil. Gas turbines are favoured when high grade heat is required for steam raising. However, large gas turbines are more complex to maintain, have lower electrical efficiencies and have a poorer efficiency at part load than engine based CHP. Community heating with CHP is a particularly efficient means of supplying large portfolios of domestic and/or commercial properties.

Overall, savings are achieved because the value of the electricity and heat produced by CHP is greater than the cost of operating i.e. the fuel consumed and the plant maintenance. In particular, the value of a unit of electricity can be up to five times that of a unit of heat. In order to maximise savings from the initial capital investment, running hours (and equivalent full load running hours) should be as long as possible.
Reciprocating Engines

Most small-scale CHP installations are based on packaged units with a spark ignition gas reciprocating engine as prime mover. The engine is used to drive an electrical generator, usually synchronous, with heat being recovered from the exhaust and cooling systems. They are often used in modular arrangements alongside boiler plant.

Packaged reciprocating engine CHP units are typically in the range of 50 kW_e to 800 kW_e output. They are run on gas and have a heat to power ratio of typically around 1.5:1. Larger custom built engines are available for bigger schemes and these typically have higher electrical efficiencies, e.g. 35%+ based on Gross Calorific Value, with heat to power ratios around 1:1. Many units can modulate down to 50% of full load electrical output and their part load efficiency is generally good.

Gas turbines

The gas turbine has been widely used as a prime mover for large-scale CHP in recent years. They are generally industrial scale plant, typically above 1 MW_e, running on gas or light oil with a higher temperature heat output than most engines. Although part load efficiency is not as high as engine based systems they have been used in large multi building sites e.g. hospitals and universities.

CHP - Key facts

- It is on-site electricity generation with heat recovery
- Typically up to 70-80% efficient
- Best sites have a year round heat demand
- In general, it is economic if it runs for more than 5,000 hours/year
- An independent feasibility study is essential, based on reliable demand profiles
- CHP should always be the lead ‘boiler’
- Economics improve if used as standby generation
- Sizing somewhat above the base heat load usually provides the best economics
- Oversizing CHP can lead to excessive heat dumping which destroys the economics
Common CHP Applications

Buildings that have historically proved suitable for CHP schemes are shown below.

**Suitable applications for CHP schemes**

<table>
<thead>
<tr>
<th>Application</th>
<th>Reason</th>
</tr>
</thead>
<tbody>
<tr>
<td>Swimming pools</td>
<td>Continuous demand for pool heating and pump power. High demand for domestic hot water</td>
</tr>
<tr>
<td>Leisure centres</td>
<td>Operate from early morning to late evening. High demand for domestic hot water.</td>
</tr>
<tr>
<td>Hospitals</td>
<td>24-hour operation. Need high ambient temperatures for patient care. High demand for domestic hot water.</td>
</tr>
<tr>
<td>Residential homes</td>
<td>Continuous occupancy with a need for high ambient temperatures for elderly residents. High demand for domestic hot water.</td>
</tr>
<tr>
<td>Hotels</td>
<td>Long operating hours, need to maintain customer comfort. Often include leisure facilities. High demand for domestic hot water.</td>
</tr>
<tr>
<td>Community heating</td>
<td>Instantly available affordable warmth, especially where elderly residents and young children accommodated. Improved building state by higher heating standards.</td>
</tr>
<tr>
<td>University campus</td>
<td>Office/teaching areas require heat during the day and for evening activities. Accommodation areas require heat early morning and evenings.</td>
</tr>
<tr>
<td>Police stations</td>
<td>24 hour, operation and occupancy. Requirement for standby generating capacity for critical operational facilities.</td>
</tr>
<tr>
<td>MOD sites</td>
<td>Accommodation areas require hot water 24 hours/day. Workshops, training areas etc. require heat during the day.</td>
</tr>
</tbody>
</table>

Applications with potential for CHP

CHP plant is less commonly applied in the applications shown below but these are nonetheless contenders for further consideration.

**Less common applications for CHP schemes**

<table>
<thead>
<tr>
<th>Application</th>
<th>Reason</th>
</tr>
</thead>
<tbody>
<tr>
<td>Offices/town halls</td>
<td>Especially where normal occupancy extends into the evening. May be combined with absorption chilling.</td>
</tr>
<tr>
<td>Museums</td>
<td>Need to maintain stable temperature/humidity conditions, independently of opening hours.</td>
</tr>
<tr>
<td>Prisons</td>
<td>24 hour occupancy providing significant hot water loads.</td>
</tr>
<tr>
<td>Schools</td>
<td>Where there is extended occupancy, particularly in:</td>
</tr>
<tr>
<td></td>
<td>• boarding schools</td>
</tr>
<tr>
<td></td>
<td>• schools with swimming pools</td>
</tr>
<tr>
<td>Retail stores/shopping centres</td>
<td>Extended operating hours. Potential benefit from an associated absorption chilling plant.</td>
</tr>
<tr>
<td>IT buildings/call centres</td>
<td>Large electrical and cooling loads. Potential benefit from an associated absorption chilling plant.</td>
</tr>
</tbody>
</table>
Any building that includes a swimming pool should be viewed as having the potential for a CHP scheme for both domestic and pool water heating.

If the heat/power profile of a building does not immediately seem appropriate, further analysis may identify alternative conditions that would improve the viability. Examples include:

- Using heat-driven absorption chilling plant to extend the base load heat demand into the summer months. Absorption chillers use less electricity than the conventional equivalents and avoid the use of greenhouse or ozone depleting gases.
- Energy linking with other nearby buildings that have a complementary heat/power profile. For example, university systems linking teaching blocks and halls of residence.

Feasibility Studies

Building designers, specifiers and operators should consider CHP as an alternative means of supplying energy in suitable applications. A brief option appraisal should be carried out when replacing major plant or designing new systems to identify if CHP might be viable, see appendix. If CHP begins to look like a leading option then a full CHP feasibility study should be carried out. Expert advice may be required at this stage in order to determine the detailed feasibility of CHP. Before any CHP assessment is done, all ‘good housekeeping’ energy efficiency measures must be carried out. The site heat and electricity demand must be properly assessed to prevent any CHP from being incorrectly sized.

Heat and power demand profiles

Economic viability is heavily dependent on the demand for heat & power, as well as the price of electricity and gas. Detailed energy demand profiles for both heat and electricity are fundamental to accurately sizing CHP and hence its ultimate viability. In the UK, there are software packages available for initial feasibility and sizing of CHP schemes in buildings, and these can be useful aids in this process.
Practical issues

A key part of any appraisal is to identify and solve the likely practical issues that need to be addressed when installing CHP. Fuel supply is the most important to consider at an early stage. If a gas supply is not available or too small then the additional cost of connection may make the project uneconomic. Similarly for the electrical connection, early discussions with the distribution network operator should take place, as there may be local network issues which may make the cost of connection high.

The CHP plant will require plant room space with good ventilation. Noise & vibration do need to be considered and may necessitate siting the plant away from the main building to avoid disturbance e.g. in hotels. Equally the exhaust needs careful siting to avoid noise and to meet any emissions regulations. Connecting the CHP to the heating system and installing appropriate controls to ensure it is always the lead boiler is probably the single greatest pitfall most sites have experienced. This requires careful design of the hydraulics and integration with the existing boiler/heating control systems.

Plant sizing

The capital investment in CHP plant may be substantial, so it is important to run plant to achieve maximum returns. Idle plant accrues no benefits, so it is important that the CHP plant operates for as many hours as possible. Basically, this means matching CHP capacity to base heat and power loads. CHP in buildings is usually sized on heat demand as shown below, as this is generally the limiting factor, although the most cost-effective solution often involves some modulating capability and/or heat dumping (e.g. dotted line in diagram) and/or heat storage. The increased savings during Winter outweigh the reduced revenue in Summer.

In practice, CHP must be sized using daily demand profiles/data like those shown above in order to accurately determine the actual amounts of heat and power that can be supplied to the building. The control strategy is a key factor in achieving good viability, as shown below. Where possible, thermal storage should be used to smooth the demand profiles and this can also have a significant effect on the overall economics of the CHP system.

Practical issues to consider:

- Fuel (natural gas) infrastructure connection
- Plant space allocation
- Possible noise attenuation problems
- Possible vibration problems
- Plant room ventilation
- Exhaust location & emissions
- Electrical connections and controls
1. Basic principles for air conditioning

All units that influence the atmosphere fall under the air conditioning heading. This lesson deals solely with units that deal with air for human use. Not dealt with are process atmospheres such as smoke extraction, dryers, cooling air, compressed air etc.

1.1 Air pressure

The atmosphere is made up of a mixture of gases that approximates 78% nitrogen and 21% oxygen. The remaining 1% consists of argon, carbon dioxide, water vapour and various rare gases.

The atmospheric pressure is the sum of the partial pressures of its components and is designated as static pressure \( p_s \). This has an effect on the system from all sides.

If the atmosphere is accelerated, a associated dynamic pressure \( p_d = \frac{1}{2} \rho v^2 \) exists.

The total pressure in the system is the sum of the partial pressures, \( p_t = p_s + p_d \).

The status of the atmosphere is determined by the pressure \( p \) [Pa], the volume \( V \) [m³] and the temperature [K]. The following is valid:

\[
V \times \frac{p}{T} = \text{constant}
\]

In the area of air conditioning, alterations are relatively small and so the status of the atmosphere is taken as being constant.

Example: How much does the volume alter if the air temperature is reduced from 30°C to 20°C at a constant pressure? It is reduced by only 3%.
1.2 Thermodynamic base principles

The energy content of the atmosphere depends upon the sensible heat of the air and upon the latent heat stored in water vapour. If the atmospheric status alters, the heat is calculated by using:

\[ Q = c_{atmo} \times m_{atmo} \times \Delta T + h_{water} \times \Delta m_{water} \]

This can be presented graphically in a simple way in an h/x (Molier / Carrier) diagram. From this, all the values for the calculations related to components associated with an air conditioning unit can be read off.
Normal presentation of psychrometric chart in UK and USA.
The diagram below shows the water vapour saturation of the atmosphere.

The maximum saturation is obtained from the 100% line. If this is exceeded, water condensation occurs (falling below the dew point).

The so-called mist area lies below the 100% line. In this area water droplets float in the air (fog) or precipitate on cold surfaces.

The atmospheric energy status is shown by the line of equal enthalpy.

Because only the energy change, $\Delta h$, is of interest for design, a zero point has been arbitrarily set in the diagram.

In order to be able to work with the $h/x$ diagram, only 2 of the 4 parameters required are necessary:

- Temperature $\vartheta$ [°C]
- Water vapour content $x$ [g/kg]
- Relative humidity $\varphi$ [%] = $x / x_{\text{max}}$
- Specific enthalpy $h$ [kJ/kg]

The remaining parameters can be obtained from the diagram. In addition, the atmospheric density $\rho$ can also be derived from it.
The climate in Germany varies between hot and dry (40°C, ϕ = 40%) and cold and humid (-30°, ϕ = 80%).

The graph shows the pattern of heating needs. These depend on the external temperature and air humidity. Additional influences on the local climate are the region, the landscape and the degree of building development. City temperatures are higher than outside because of building development.

The frequency of distribution for air temperature and air humidity varies a great deal regionally. The graphs shows the distribution for Nürnberg that shows a peak at an air humidity of ca. ϕ = 60% and an external temperature of about 0°C.

The relative humidity ϕ is not constant over the course of a day because the temperature fluctuates whilst water vapour saturation hardly changes.
1.4 Comfort level

The term "comfort" is not something that can be measured precisely. Attempts have been made to convert this term into measurable parameters (ASHARE 55-81, ISO 7730, DIN 1946). Whether a person feels comfortable or not in a room depends upon many factors:

- Room design (daylight, colours, height, plants, wall temperature)
- **Noise pollution** (machinery, people, surroundings, **air conditioning**)
- Room atmosphere (quality, hygiene, odour, air speed, temperature, humidity)

Air conditioning has an influence on the areas highlighted in bold print. Depending upon the intensity of body activities and air pollution, 20 – 30 m³/h fresh air is necessary for the removal of CO₂ and moisture and, in the case of smokers, a additional 20+ m³/h of fresh air.

Humans produce waste heat because of their metabolism. Depending on the activity, this waste heat output amounts to 100 – 300 W.

This waste heat must be released from the human body into the surroundings. This occurs in 2 ways – heat radiation (convection) and evaporative cooling.

Heat radiation and convection are more effective if a greater amount of skin is exposed and the cooler the surrounding walls and air are.

Evaporation depends upon the air’s relative humidity. The lower the air humidity the greater the uptake capacity of the air. If the humidity level $\varphi$ is in excess of 80% the evaporation rate is too low and people perceive the atmosphere as being oppressive. If the air speed is increased, the greater associated air volumes can compensate for this effect. In this way the perceived air temperature alters and the air is felt as being cooler (e.g. ceiling fan).

We understand the influence of the surroundings on humans under the term thermal comfort. A comfort zone of 18°C to 24°C air temperature and a relative humidity $\varphi$ of 30% to 70% has arisen as a result of this. For health reasons, the room air temperature should not lie more than 6 K below the external temperature.
2. Air conditioning

2.1 Functions

The following terms and abbreviations are used with regard to the atmosphere:

- EA external air
- IA inflow air
- RA recirculated air
- XA extracted air
- OA outflow air
- MAX maximum working area pollutant concentration in the air

Because the status of the external air in Germany exceeds the thermal comfort level for most of the time, the inflow air is heated, cooled, humidified and dehumidified. Moreover, air circulation units must also eliminate the internally generated heat and moisture loadings.

The air exchange required can be achieved either by passive ventilation (window, shafts) or by means of air conditioning. The external air volume flow required [m³ / h] is calculated according to the number of people, the air pollution level (MAX) or the heating load that is to be drawn off or led in.
2.2 Components

DIN 1946 symbols for air conditioning and the function:

- **Compressor/ventilator:**
  - Acceleration and pressure increase

- **Heat transfer / Cooling index:**
  - + heat inflow
  - - heat removal

- **Heat / coolness recovery:**
  - Recuperative, heat transfer only
  - Regenerative, additional moisture transfer

- **Air humidifier – in this case a spray humidifier:**
  - Adiabatic humidification

- **Filter:**
  - Cleaning the air
1. Basic Principles

1.1 Thermodynamic base principles – Heat flow

Heat level: Depending upon the level, heat is perceived as cold or warm. A tension exists between these energy levels.

Heat flow: Because of this tension, if two heat levels are connected by means of a conductor, a heat flow exists from the higher to the lower heat level and this continues until the same level is reached for both.

Heat flow = Tension (temperature difference) / Heat conduction - Resistance
1.2 Thermodynamic base principles – The heat pump

If there is a need to reverse the heat flow, heat from the cooler area must be transported (pumped) to the warmer area. The types of units required for doing this are called heat pumps or refrigeration equipment, depending upon their function.

Work must be performed by the unit in order to raise the heat to a higher level.

The diagram shows the heat and energy flow for a heat pump.

\[
Q'\text{o} = \text{heat extraction} = \text{refrigeration performance} \\
P = \text{power uptake by the unit} \\
Q'\text{c} = \text{heat outflow} = \text{waste heat}
\]

The energy costs that must be paid for a refrigeration unit can be determined from the power uptake \( P \). For the comparison of different types of refrigeration units in this area of technology, the relationship of utilization /expense = \( Q'\text{o} / P = \text{COP} \) is used.

From the technical perspective, refrigeration units can be designed to work in many ways e.g. with semi-conductors (Peletier element), through which electricity flows. However, the most commonly used types of refrigeration units operate using a cooling agent.
2.1 Basic principles for refrigeration agents

Liquid materials suitable for use as cooling agents are all those which can be heated and condensed as often as desired without any associated chemical decomposition. In this regard, the dependence of the boiling temperature \( T \) [°C] on the surrounding pressure \( p \) [bar or Mpa] is used. If the surrounding pressure is raised, the boiling point temperature is raised and vice versa!

The graph shows the relationship curve for the boiling point temperature of a cooling agent. At a pressure of ca. 2.5 bar, it has a boiling point temperature of \(-20°C\). If the pressure is raised to ca. 15 bar, the boiling point temperature rises to \(40°C\).

Cooling agents are chosen for their ability to boil (vaporise) at low pressure at the desired temperature for the cool room. Subsequently, the pressure is raised by the refrigeration equipment to the point required to effect the heat removal necessary.

Some organic cooling agents can be mixed (without them separating again once in operational use) and so the desired characteristics can be adjusted. The diagram shows mixtures that enable the desired boiling point to be adjusted.
2.2 Refrigeration agent limits

The use of a refrigeration agent is limited by its chemical characteristics. Fundamentally, these are their stability with regard to pressure and temperature. These are shown in so-called p/h diagrams for individual refrigeration agents (in this case R22). From such diagrams the maximum pressures and temperatures that refrigeration agents can withstand can be ascertained. A further important factor is their compatibility with the lubricant used in the refrigeration unit.

2.3 Energy removal

The refrigeration agent vapourises (boils) and, because of this, extracts heat from the freezer room. During the transitional phase from a liquid to a gas, the temperature of the refrigeration agent does not change. The boiling point temperature is set by the pressure in the evaporator. More than 90% of the energy transfer occurs as a result of this transitional phase.
2.4 Refrigeration agent nomenclature

The abbreviation used for cooling agents is the letter R followed by a three-digit number. Cooling agents are differentiated into organic (R10...600, where 400..500 are used for blends) and inorganic (m R700).

Organic refrigeration agents consist of short chain hydrocarbons (HC) and are volatile (low boiling point). Organo-halogen refrigeration agents (with chlorine, Cl., and fluorine, F) were introduced as safe refrigeration agents because they were neither combustible (and thus explosive) nor toxic.

Unfortunately, these chlorofluorocarbon agents have been proven to be damaging to the world’s ozone layer. Their destructive potential is measured as ODP (ozone destruction potential). For this reason they are now being substituted by hydrofluorocarbon agents which are not supposed to be so damaging. All organo-halogen refrigeration agents also contribute strongly to increases in the greenhouse effect. This is shown by the GWP value (Greenhouse Warming Potential = 10,000). This value compares the influence of one molecule of the refrigeration agent with one molecule of CO2.

In the case of inorganic refrigeration agents, ammonia dominates (NH3, R717). Unfortunately this agent is poisonous and inflammable (explosive). However, because of its outstanding characteristics it is used in conjunction with high safety standards. Other cooling agents are water (H2O, R718), which is used in the low-pressure area (<1 bar), and carbon dioxide (CO2, R744).
3 Refrigeration units

Refrigeration units that use refrigeration agents normally work using closed circuits. An example of an exception is the chemical industry where the refrigeration agent can be an intermediary product that can be re-processed after condensation.

A refrigeration unit consists of an evaporator, a working unit (compressor), and a liquefaction unit (condenser). In the evaporator, heat is taken up because the refrigeration agent vaporises. The working unit compresses the refrigeration agent. A pressure increase occurs. In the condenser, the refrigeration agent is cooled down and thus condensed in the presence of a medium that removes heat e.g. external air. In a closed refrigeration agent circuit, a pressure reduction results and the refrigeration agent is returned to the evaporator.
1. Basic Principles

Electricity is considered to be one of the most versatile energy forms. It can be used for the production of light, power output, cold and heat. Because electricity is very expensive to produce and storage is costly, it belongs to the most expensive of energy forms.

1.1 Electrical Network

The electrical network starts at production units and finishes at final consumers.

Power is produced with generators that have 3 phases, alternated voltage. The voltage level is increased by power transformers to levels up to 400 kV.

After this operation, the electricity is applied to many transmission lines and transported to power stations in order to reduce the tension level. This cycle could happen two or three times until reaching the common used voltage (400 V). In the next figure, it is possible to understand the several steps that occur from electricity production to final users. There is safety equipment, transformer stations, break switch. In this installation, besides these equipment exists also the measuring transducer in order to get the consumption at real time.
1.2 Losses
Any equipment produces losses. Starting in power station until the final equipment of the line.
In almost all of them, the losses measurement can be quantified. It is possible by the equipment specification according with application.
This fact is very important because in the majority of cases it is possible to reduce losses by choosing well the equipment according to the application and in others cases by controlling and adapting the equipment to the process.

1.3 Transformers

This equipment is applied in many ways.
It could be used immediately in power station, increasing the voltage level in order to keep the losses in the transmission path to a minimum, by reducing the current.
It could be used for decrease high voltage into the level of the voltage to be used by the final consumer.
The picture exemplifies the ideal transformer, but like any equipment it produce losses.
Its efficiency is normally round 98 %.

The losses measurement just could be interesting in distribution transformers with a significant consumption.
The generation and transmission of electrical power are more efficient in polyphase system employing combinations of three phases.

1.3 Power Factor Concept

This term is applied to the alternate current and it means or measure the difference angle between the current and voltage.

Alternating current has a frequency of 50Hz [1/s] (60 Hz in USA); that means 100 passes through zero per second.
In the next figure it is possible to see that the current waveform passes through zero after the voltage wave that means that the load has a inductive character.
The majority of cases it is what happens.
The better example to justify this fact is that, in the majority of installation the biggest Consumption is from electrical motors that have normally power factor around 0,8.

This picture could represent the process load. Besides the resistance R, the components of an alternating current circuit also include an inductive portion L and a capacitive portion C. The induction L (coil) causes a sequential pre-effect on the alternating current, die capacitance C (condenser) a post-effect. As a rule L>C is a valid measure for power consumers.

The idle current Q only places a load on power lines without performing any useful work output. In addition, the cable becomes heated by the current flow and so the resistance increases. That is why the idle current should be held down at the lowest possible level.

1.3.1 Power Factor Compensation

This can be achieved by switching on condensers (compensation). This operation not only should be done to reduce the idle current into power lines but also to keep power factor above the minimum according to the electricity supplier. The consumer that has consumption of reactive energy above the established limit has to pay to the supplier not only the active energy consumed but also the reactive energy above the allowed limit.
2. Motors

The performance data for power motors (>1kW) is always related to the delivered shaft output $P_w$, not to the electric power taken in.

\[ \eta = \frac{P_w}{P_e}, \quad \text{Waste heat } Q \text{ motor } = P_e - P_w \]

2.1- Direct Current Motor

The direct current motor distinguishes itself by means of a linear characteristic (current = torque, voltage = revolutions per minute (rpm)), is simple in assembly and uncomplicated in regulation (tachometer, Thyristor). The motors require maintenance (brushes, bearings).

R&D on electronic power devices had been a very big impact in many technologies. Variable Speed Drives is one of them. They have improved very much its characteristics and nowadays they can perform on three-phase induction motors speed/torque control actions that, for some applications, are similar to ones achieved by direct current motors.

Electrical induction motors are less expensive, initial cost and maintenance, than direct current motors. For that reason all dc motors utilization should be analysed in order to be sure if the substitution is possible or not.

2.2.3-Phase Current – Asynchronous Motor

The electromagnet in the asynchronous motor produces a rotating field, is stimulated by the mains supply and induces an alternating current in the rotor, even when not in motion. Common models are squirrel-cage rotors and slip-ring rotors. The torque curve does not follow a straight-line path but rather follows the path characteristic for the motor being examined. Because the start up current is larger than the rated current (1.8 –3.5 times), these are often governed with the Y-delta connection. The motor has a fixed number of rpm that depends upon the number of pairs of poles: \( \text{rpm } n = \text{ frequency} \times 60 / \text{ pole pairs} \). The synchronous rpm is dependent upon mains power frequency.

Rpm regulation can be achieved by means of pole conversion or a frequency inverter.
2.3.3-Phase Current – Synchronous Motor

The synchronous motor is actually used as a generator. It cannot start on its own and therefore must be controlled by an electronic switch. Once the motor has almost reached the set rpm, it runs further on its own. These motors have a high degree of efficiency and allow for variable rpm levels because of the electronic regulation.

2.4 High Speed Motor

Up to 80,000rpm for turbo compressors etc

2.5 Linear Motor

Linear motors are 3-phase or direct current motors, that perform a linear motion, such as pneumatic/hydraulic cylinders.

2.6 Selection of the Motor

The selection of the electric motor is made according to the response characteristic desired in the installation and the required torque. Required torque is related with power and speed of the motor. Another important factor is choosing well the construction material of motor according to environment and hazards areas.
2.7 Gearboxes

One of the most difficult problems for process engineers has been to adequate the speed of the electrical induction motors with the necessary process equipment speed.
As we know electrical induction motor speed are related with the speed of the magnetic field that depends on the supplied voltage frequency. For that reason we are constrained to theoretical speeds of 3.000, 1.500, 750 rpm. Real speed is a little bit lower.
If the equipment required rotating speed is not one of above mentioned, what usually happens, the use of a gearbox is necessary.
Related to gearboxes each one has its own advantages and disadvantages, loss factors, depending upon its type and construction.
At same time, if same speed variation was need, mechanical speed variation equipment is available (conical pulleys belt drives, spheres on conical surfaces and hydraulic) but all of them with poor efficiency and little variation range. Most part of them is nowadays-archaeological technology.

3. Variable speed drives – Application

The main purpose when using the variable speed drives is to reduce the energy consumption.
They commonly used in:
- Air Compressors in order to adjust the energy supply to the desired air consumption.
- Blowers adjusting the power to the demand air/gas output
- Pumps
- Any electric motor to change its power according with the process requirements
- To perform specially actions like getting a sudden stop of the motor or to change in a fast way the sense of rotation.

4- General remarks

- Optimisation the equipment to the process should be done in order to get the better efficiency.
- It is important to listen the employee’s ideas, especially those coming from the maintenance people. They knows well how the process works and could give us ideas how to improving it.
- Involve production people on data acquisition system in order to involve them into the company general goals.
- Use the checklist to find where the possibilities of improvements.
1. Technical Quantification of Light

1.1 Light output \( \Phi \) [lm]

The light output from a lamp is measured in lumen. The light yield is the degree of effectiveness of a lamp (Light output from the lamp per Watt as related to system output), Nomenclature: \( \eta \) [lm/W]

1.2 Light intensity \( I \) [cd]

The measurement for the light radiated in a particular direction is measured in candela. It is portrayed in a polar diagram as a light intensity distribution curve.

1.3 Light density \( L \) [cd/m²]

The impression of brightness and dazzling of the eyes is determined by the light density. The light density is the light intensity as related to the area being looked at. For example, the rule valid for computer workstations is less than 200 cd/m² at a 50° radiation angle from the light.

1.4 Lighting intensity \( E \) [lx = lm/m²]

The light output falling on the working area

Unit of measurement: Lux, quantitative interpretation for light planning

The lighting level of a room is defined by the specified lighting intensity (Lux). For individual room types, the standards define various specified lighting intensities.
1.5 Light colour

Diffuse daylight from the sun on a day with full cloud cover is perceived by the human eye as being white in colour. Direct sunlight is warmer (redder). Artificial light sources are categorized upon the basis of their colour temperature:

- over 5000 K  Day light white  tw
- 3300-5000 K  Neutral white  nw
- over 3300 K  Warm white  ww

For reasons of comfort, it is recommended to use colder light colours (nw, tw) with higher lighting intensities and warmer light colours (ww) with lower lighting intensities.

1.6 Colour Reproduction

For seeing and recognising colours, the following points are important:

- Each surface reflects predominantly its own colour, the balance being largely absorbed.
- Only colour reflected into the eye can be seen.
- If colours are lacking in the incoming light, then the surface colour cannot be recognised (grey).
- The spectral sensitivity of the eye corresponds to a Gauss distribution. It is at a maximum (days) in the yellow-green area (ca. 560 nm).

The colour reproduction quality of a light source is expressed by the colour reproduction index $R_a$, which presents it as the approximate percentage of the colours actually seen in the light emitted from tw and nw lamps as well as lamps of the type ww in comparison to daylight.

Classification according to the CIE Standard:

- 1a  $R_a$ 100-90  e.g. Graphics
- 1b  $R_a$ 90-80  e.g. High value sight based tasks
- 2  $R_a$ 80-60  e.g. Office
- 3  $R_a$ 60-40  e.g. Store
- 4  $R_a$ 40-20  e.g. Some heavy industry
- 5  $R_a$ under 20  e.g. Outdoors

For each visual task, the technical light standards prescribe the quality features for the lighting. For high value tasks where colour reproduction has to be dealt with, e.g. for graphics, textile colours, etc., particular care must be taken with regard to the light spectrum of the light source.

1.7. The Room Utilisation Factor

This expresses how much light from the surrounding surfaces is reflected on to the working area. It is influenced by two parameters:

- The degree of reflection from the surrounding surfaces (ceilings, walls, floors). The darker the surface colours are, the less the amount of reflected light.
- Dimensions of the room (room index). The room index of a cube is clearly greater than that for a long sided rectangle.
2. Lamps (Light sources)

2.1 International Nomenclature

General use lamp A 60, A65
Parabolic reflector lamp PAR 20, PAR 30, PAR 38
Halogen lamp QT 12 QT 18 QT-DE
Metal vapour halogen lamp HIT, HIT-DE
Sodium vapour high pressure lamp HST, HST-DE
Fluorescent lamp T 7, T 16 , T 26 , T 38
Compact fluorescent lamp TC-D, TC-T, TC-L

Examples of the various types of lamps:

1. Halogen lamp
2. Low voltage halogen lamp
3. Compact fluorescent lamp
4. Fluorescent lamp
5+6. Metal vapour halogen lamp
7. Sodium high pressure lamp
2.2. Characteristics of Lamp Types

<table>
<thead>
<tr>
<th>Nomenclature</th>
<th>Light yield lm / W</th>
<th>Colour reproduction</th>
<th>Longevity ca.</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Incandescent lamps A, PAR, QT</td>
<td>14-22</td>
<td>1a</td>
<td>1,000 h</td>
<td>Parts of the lights become very hot</td>
</tr>
<tr>
<td>Metal vapour halogen lamp</td>
<td>70-110</td>
<td>1a, 1b</td>
<td>6,000 h</td>
<td>For tall rooms and halls</td>
</tr>
<tr>
<td>Sodium vapour high pressure lamp</td>
<td>70-140</td>
<td>4</td>
<td>6,000 h</td>
<td>For rooms with low needs of colour reproduction</td>
</tr>
<tr>
<td>Fluorescent lamp</td>
<td>60-104</td>
<td>1b</td>
<td>11,000 -40,000 h</td>
<td>Standard lamp for use in industry</td>
</tr>
<tr>
<td>Compact fluorescent lamp</td>
<td>25-80</td>
<td></td>
<td>4,000 -12,000 h</td>
<td></td>
</tr>
</tbody>
</table>

2.3 Discharge Lamps

For industry and business, the lamps used are discharge lamps (fluorescent, high pressure sodium vapour, metal vapour halogen). For discharge lamps, a gas or plasma is used to produce light.

To be precise, a glow wire is also included (as for incandescent lamps) which emits electrons that cause the gas or plasma to glow. The plasma conducts the electric current better if it is hotter. It is not an ohmic conductor. In order to limit the current flow, discharge lamps require a ballast unit and starter.

New developments in the area of discharge lamps are lamps with external ignition, i.e. without a glow wire. In this way, an almost unlimited longevity for a lamp can be attained (> 60,000 h). The ignition and activation of the plasma is achieved by induction or microwave.

Another trend is utilising white LEDs for lighting. The LEDs emit a strongly directed light beam such as that from a laser. By means of their arrangement and optical prisms, it is possible to make lamps with almost unlimited longevity (> 60,000 h).
2.4 Ballast Units

The ballast unit must limit the current flow into the discharge lamp. Conventional ballast units CB are spools, i.e. ohmic resistors, which are switched on in series with the lamp. The spool produces induction which is why there is also capacitor ballast in order to limit the blind current. Low loss ballast units LLB are like the CB except that lower losses occur because of the choice of spool material.

These ballast units require a starter in order to ignite the plasma.

Electronic ballast units EB fulfill the same function as the CB / LLB units. The starter is integrated within it. Depending upon the model, the light can also be dimmed.

Ballast units have their own electrical power need (power loss). The total power requirement for a light is accounted for as follows:

\[
\text{Pel System} = \text{Pel Lamp} + \text{Pel ballast unit}
\]

Some characteristic nominal values:

**Fluorescent lamp 58 Watt:**

<table>
<thead>
<tr>
<th>Type of ballast unit</th>
<th>Pel Ballast unit</th>
<th>Pel System</th>
</tr>
</thead>
<tbody>
<tr>
<td>CB</td>
<td>13 Watt</td>
<td>71 Watt</td>
</tr>
<tr>
<td>LLB</td>
<td>8 Watt</td>
<td>66 Watt</td>
</tr>
<tr>
<td>EB</td>
<td>-3 Watt (voltage reduction)</td>
<td>55 Watt</td>
</tr>
</tbody>
</table>

**Fluorescent lamp 36 Watt:**

<table>
<thead>
<tr>
<th>Type of ballast unit</th>
<th>Pel Ballast unit</th>
<th>Pel System</th>
</tr>
</thead>
<tbody>
<tr>
<td>CB</td>
<td>10 Watt</td>
<td>46 Watt</td>
</tr>
<tr>
<td>LLB</td>
<td>4 Watt</td>
<td>40 Watt</td>
</tr>
<tr>
<td>EB</td>
<td>0 Watt (voltage reduction)</td>
<td>36 Watt</td>
</tr>
</tbody>
</table>

2.5 Starter

The starter produces a voltage pulse which is necessary for igniting the plasma. Because the number of switching-on cycles decisively influences the longevity of lamps, there are so-called warm starters, which start lamps in a protective fashion and can considerably increase their longevity.
3. Lighting

3.1 Degree of Effectiveness of Lighting

The degree of effectiveness of lighting, $\eta_{\text{Lighting}}$, depends upon the way it has been made. The better the light reflecting surfaces and the less disrupted the light flow emitted from the light then the greater the effectiveness becomes. The removal of heat build up from around the lighting also plays an important role because most lighting materials work optimally at 25°C. Above this they will lose light emission effectiveness. In addition, the distribution of the emitted light plays a decisive role with regard to the total degree of effectiveness. For this reason, asymmetric light distributors can be used to considerable advantage at windows in order to restrict the escape of light through the window.

3.2. Industrial Lighting

In industrial and commercial areas 4 types of lighting units have become generally accepted:

1. Production rooms, industrial halls (4-7m)  
Light reflectors

2. High halls (> 6 m):  
Hall radiator for metal vapour halogen lamps

3. Rooms with high protection classes such as medical and humid rooms:  
Diffusion lights with prismatic or opal covering

4. Offices:  
Mirror screen lights

The current degree of lighting effectiveness can be determined from manufacturers data sheets.
**Preparation material**

**Compressed air**

**Introduction:**
Compressed air is used increasingly preferentially because it possesses a range of outstanding characteristics:

- Can be easily transported
- After use no return is necessary
- Easy to store
- Clean and dry
- Light
- Simple and robust equipment
- Safe from overloading
- A fast working medium
- Easy to regulate

The disadvantage is that only 10% of the input energy is transformed into compressed energy. 5% is transformed into the exergy component and is therefore irreversible (non-returnable). 85% of the input energy is lost as heat. Because of this, compressed air is a very expensive energy application. As a result, compressed air should be generated, treated and used very efficiently in order to avoid high electricity costs.

**Use Areas for Compressed Air:**

**Pneumatic Drives**
Example: Hammering compressed air tool
Picture: Valveless pneumatic jackhammer

**Spraying**
Example: Sandblasting, spray painting
Picture: Metal spraying arc unit

**Transporting**
Example: Conveyor units
Picture: Height bridging with a Pneumatically driven elevator

**Blowing**
Example: Blowing out, cleaning
Picture: Blow gun with spiral hose
Theoretical Principles:

**Atmospheric pressure** is produced as a result of the weight of the atmosphere around the earth. It is dependent upon the density and height of the atmosphere. At sea level the following is valid:

\[ 1.013 \text{ bar} \quad = \quad 760 \text{ mm/Hg (Torr)} \]

**Absolute pressure and gauge pressure:**

In compressed air technology all pressure information refers to gauge pressure. A level of 6 bar in the compressed air network means an absolute pressure of 7 bar.

**Operating volume = compressed air in the compressed state**

In the operational state, the volume is relative to the actual state. Temperature, air pressure and humidity must be taken into account as parameters. When discussing operating volume, the pressure is always mentioned e.g. 1m³ at 7 bar positive pressure means that 1m³ of air is compressed at 7 bar positive pressure (= 8 bar absolute) and only takes up 1/8 of the original volume.

0 bar absolute  8 bar absolute

**Pressure ranges:**

Low pressure: Most applications in industry and trade lie within this pressure range. Compressor: 1-2 stage piston and screw compressors

Med. pressure: Heavy vehicle tyres, special machinery

High pressure 1: Pipe pressure testing, blow moulding of plastic containers. Compressor: 3-stage piston and screw compressors

High pressure 2: Leak testing, power stations and rolling plants, oxygen compression. Compressors: 3-4 stage piston compressors
The principle of air compression:
In air compression, a polytropic compression takes place i.e. the work applied to achieve volume adjustment is mostly transformed into heat (the air heats up due to compression). Part of the heat is transferred through the cylinder wall (piston compressor). Part of the work applied to volume adjustment is incorporated into the compressed air in the form of compressed energy.

The Energy balance (c = compressor):

Out of 100 % of the electrical energy inputted, ca. 10% is transformed into the form of compressed air energy and 90% into heat of which 85% can be reused by means of a heat exchanger (OC = oil cooler). 5% is lost into the surroundings as radiated heat.

Components of a Compressed Air Unit:
These components can be broken down into four main modules:
1. Compressor (inlet filter, compression elements, coolers, control system)
2. Filter systems (the removal of solids and oil particles from the compressed air according to the quality requirements)
3. Drying (dehumidification of the compressed air in driers)
4. Compressed air receiver and compressed air network (storage and distribution of the compressed air)

**Compressors:**
The compressors are classified into different types. These are used depending on end purpose and size of machine.

- **Positive Displacement Machines**
  - Reciprocating piston compressor
  - Roots blower
  - Vane compressor
  - Screw compressor

- **Dynamic Machines**
  - Centrifugal compressor
  - Axial compressor
  - Side channel compressor

The underlined compressor variants are the types of machines used most often. The focus of our considerations is directed at these types of structural units.

Air-cooled variants of the reciprocating piston compressor are commonly used for small sizes (up to 4 kW), although they can go up to 90 kW. Water cooled variants of this compressor are also used for larger capacities and have efficiency advantages through having double action pistons over the screw and vane compressors. However, the purchase cost is also much higher and very few new machine are sold for air generation.

Manufacturers are increasingly concentrating on manufacturing large numbers of screw elements. As a result, there are few manufacturers of screw elements today but many types of screw compressors. This means that the same type of screw elements may be found within a range of different housings. For the same reasons, the market share for vane compressors (ca. 5%) is continuously declining. In the medium term, vane compressors are likely to be driven off the market apart from at they very small end. Therefore, it is sensible for users to concentrate on the screw-based technology.
Compressed air treatment (compressed air quality)
A further important aspect to consider is the compressed air quality required, i.e. “compressed air treatment”. Under the term compressed air treatment the required treatment and finishing of compressed air, according to the compressor type, in order to offer best possible solution to the end user is considered. The following possibilities are available:

- **Filtration**, in order to prevent contamination and to guarantee the desired purity of the compressed air. Various filter systems are available for filtration (separation is related to the size of particulate matter in the flow):
  
  I. Simple filter (separation 5 mg/m³)
  II. Micro- or fine filter (separation 0,01 mg/m³)
  III. Activated carbon filter (0,003 mg/m³)
  IV. Sterile filter (for 100% germ free compressed air)

The separation capability of these filters is based upon an operating temperature of 20°C. Higher temperatures impair the effectiveness of the filter. The filters complement each other, i.e. first stage I, then II etc. Example: Quality required: 0,003 mg/m³ - thus filters I, II und III are connected in series. In this regard be aware that each installed filter creates a pressure loss and associated cost. It is therefore essential to think carefully about the level of air quality that is required.

- **Drying** of the compressed air or removal of condensation. For drying, the following systems available are:
  
  I. Aftercooling (included on compressor, no external treatment)
  II. Refrigerant drying (typical pressure dewpoint +3°C)
  III. Adsorption drying (Dessicant or sorption dryers) (typical pressure dewpoints –20, -40, -70°C)

The above named systems are not mutually exclusive in this regard and thus, in principle, can be complementary. A tabulated overview of the quality classes and requirements for various use areas is found in Appendix 1.

Compressed air network and compressed air receiver:

The compressed air network must fulfill various conditions:

- Sufficient flow volume and working pressure for each user
- Supply the user with compressed air at the required level of quality
- Low pressure drop and a high degree of reliability

The compressed air receiver has to fulfill the following duties:

- Storage: Short term peak flows can be covered from the volumes stored in the compressed air receiver. The compressor cycles less frequently and can therefore work more continuously.
- Pulsation damping: Pulsation of the flow volume caused by piston compressors is damped by the compressed air receiver.
- Condensation separation: The moisture contained in the air condenses in the compressed air receiver and collects in the base from where it can be drained away.
Appendix 1: Compressed Air Quality; Quality Classes According to the ISO 8573-1:2002 Standard:

Humidity and oil

<table>
<thead>
<tr>
<th>Class</th>
<th>Pressure dewpoint, °C</th>
<th>Oil carry over, mg/m³</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>As specified by the equipment user or supplier and more stringent than class 1</td>
<td>&lt;=0.01</td>
</tr>
<tr>
<td>1</td>
<td>&lt;= -70</td>
<td>&lt;=0.1</td>
</tr>
<tr>
<td>2</td>
<td>&lt;= -40</td>
<td>&lt;=0.1</td>
</tr>
<tr>
<td>3</td>
<td>&lt;= -20</td>
<td>&lt;=1</td>
</tr>
<tr>
<td>4</td>
<td>&lt;= +3</td>
<td>&lt;=5</td>
</tr>
<tr>
<td>5</td>
<td>&lt;= +7</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>&lt;= +10</td>
<td></td>
</tr>
</tbody>
</table>

Particulate

<table>
<thead>
<tr>
<th>Class</th>
<th>Maximum number of particles per m³</th>
<th>Particle size</th>
<th>Concentration</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>≤0.1</td>
<td>0.1&lt;d≤0.5μm</td>
</tr>
<tr>
<td>0</td>
<td>As specified by the equipment user or supplier and more stringent than class 1</td>
<td>Not applicable</td>
<td>Not applicable</td>
</tr>
<tr>
<td>1</td>
<td>Not specified</td>
<td>100</td>
<td>1</td>
</tr>
<tr>
<td>2</td>
<td>Not specified</td>
<td>100,000</td>
<td>1,000</td>
</tr>
<tr>
<td>3</td>
<td>Not specified</td>
<td>10,000</td>
<td>500</td>
</tr>
<tr>
<td>4</td>
<td>Not specified</td>
<td>Not specified</td>
<td>1,000</td>
</tr>
<tr>
<td>5</td>
<td>Not specified</td>
<td>Not specified</td>
<td>20,000</td>
</tr>
<tr>
<td>6</td>
<td>Not applicable</td>
<td>&lt;=5</td>
<td>&lt;=5</td>
</tr>
<tr>
<td>7</td>
<td>Not applicable</td>
<td>&lt;=40</td>
<td>&lt;=10</td>
</tr>
</tbody>
</table>

In all cases the reference conditions for the volume measurements are 1 bar absolute, 20°C, 0%RH.
### Recommended Quality Classes According to Purpose of Use
(In Accordance With the Association of German Compressed-Air Specialists):

<table>
<thead>
<tr>
<th>Application</th>
<th>Solids</th>
<th>Water</th>
<th>Oil</th>
</tr>
</thead>
<tbody>
<tr>
<td>Storage air</td>
<td>3</td>
<td>5</td>
<td>3</td>
</tr>
<tr>
<td>Instrument air</td>
<td>2</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Air motors</td>
<td>4</td>
<td>4-1</td>
<td>5</td>
</tr>
<tr>
<td>Small air motors</td>
<td>3</td>
<td>3-1</td>
<td>3</td>
</tr>
<tr>
<td>Air turbines</td>
<td>2</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>Machinery for shoes, stone or glass</td>
<td>4</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>Cleaning of machinery parts</td>
<td>4</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>Construction areas</td>
<td>6</td>
<td>6</td>
<td>6</td>
</tr>
<tr>
<td>Delivery of grits</td>
<td>3</td>
<td>4</td>
<td>3</td>
</tr>
<tr>
<td>Delivery of powders</td>
<td>2</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td>Foundry machinery</td>
<td>4</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>Delivery of foods and drinks</td>
<td>2</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>Hand tool industry</td>
<td>4</td>
<td>5-4</td>
<td>5-4</td>
</tr>
<tr>
<td>Tooling machines</td>
<td>4</td>
<td>3</td>
<td>5</td>
</tr>
<tr>
<td>Mining</td>
<td>6</td>
<td>6</td>
<td>6</td>
</tr>
<tr>
<td>Packaging and textile machinery</td>
<td>4</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Photographic film finishing</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Compressed air cylinders</td>
<td>3</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>High sensitivity pressure regulation</td>
<td>3</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>Process control equipment</td>
<td>2</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>Hammer drills</td>
<td>6</td>
<td>6</td>
<td>6</td>
</tr>
<tr>
<td>Stationery sandblasting units</td>
<td>-</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Mobile sandblasting units</td>
<td>6</td>
<td>6</td>
<td>6</td>
</tr>
<tr>
<td>Spray guns</td>
<td>3</td>
<td>3-2</td>
<td>3</td>
</tr>
<tr>
<td>Welding machines</td>
<td>4</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>General plant air</td>
<td>4</td>
<td>4</td>
<td>4</td>
</tr>
</tbody>
</table>
Definition

The thermal utilisation of biomass is the oldest form of energy production used by mankind. Thermal utilisation of biomass means the direct combustion of biomass in order to produce heat, electricity and steam.

1. FUELS

A range of materials is available as fuels for thermal utilisation. Alongside residues from forestry such as branches, stumps and bark, there are residues from agriculture such as surplus straw, cereal and rape screenings, rice husks, nut husks, coffee husks, sunflower husks and compressed cake from plant oil production as well as specific energy plants such as wood from short rotation plantations, perennial grasses and the Chinese reed.

In the following table, the energy contents for some of these raw materials in comparison to fuel oil are presented. The higher calorific values correspond with lower water contents and vice versa.

<table>
<thead>
<tr>
<th>Water content</th>
<th>Calorific value $H_u$</th>
<th>Debris density</th>
</tr>
</thead>
<tbody>
<tr>
<td>%</td>
<td>kWh/kg</td>
<td>kg/m³</td>
</tr>
<tr>
<td>Straw - loose 10-20</td>
<td>3.6-4.2</td>
<td>80</td>
</tr>
<tr>
<td>Rice husks    10-15</td>
<td>3.6-4.2</td>
<td>50-100</td>
</tr>
<tr>
<td>Whole cereal plants - loose 10-15</td>
<td>4.4-5.0</td>
<td>100</td>
</tr>
<tr>
<td>Wood - chipped 15-60</td>
<td>1.7-5.0</td>
<td>200-250</td>
</tr>
<tr>
<td>Light fuel oil</td>
<td>11.6</td>
<td>900</td>
</tr>
</tbody>
</table>

The calorific values shown in the above table are lower calorific values according to the following definition:

$$H_u = H_o - r \cdot w,$$
where

- $H_u$ = lower calorific value (kJ/kg)
- $H_o$ = upper calorific value) (kJ/kg)
- $r$ = heat of vapourisation of water (2442 kJ/kg at 25 °C)
- $w$ = free released water (kg)

This definition clearly shows the strong dependence of the energy yield upon the water content of the fuels. With a water content of more than 30%, the majority of heat is needed to vapourise the water. In this regard, a reduction in the degree of effectiveness is associated with an increase in emissions.
2. **BIOMASSE POTENTIAL**

For the production of energy from the fuels referred to above, one assumes the following proportions:

<table>
<thead>
<tr>
<th>Potential</th>
<th>Origin</th>
</tr>
</thead>
<tbody>
<tr>
<td>50%</td>
<td>Residual wood from timber production</td>
</tr>
<tr>
<td>32%</td>
<td>Surplus straw and residues from agriculture</td>
</tr>
<tr>
<td>13%</td>
<td>Residual wood from the woodworking industry</td>
</tr>
<tr>
<td>3%</td>
<td>Street greenery, cemeteries and public parks</td>
</tr>
<tr>
<td>2%</td>
<td>Plywood and household waste wood</td>
</tr>
</tbody>
</table>

The division of the potential, as shown in the above table, is only an indicative value of proportions of the individual biogenic fuels in regard to the overall potential of these fuels and makes no statement about the total energy potential in any one particular region.

The cultivation of renewable raw materials for thermal utilisation is still in the early stages of study meaning that the final potential which might result, from the business point of view, cannot be estimated. For the types that are currently common, one can assume the following related potentials on an yield per area basis:

<table>
<thead>
<tr>
<th>Potential</th>
<th>Origin</th>
</tr>
</thead>
<tbody>
<tr>
<td>59 MWh/ha*a</td>
<td>Perennial grasses</td>
</tr>
<tr>
<td>56 MWh/ha*a</td>
<td>Short rotation tree plantations (wood)</td>
</tr>
<tr>
<td>48 MWh/ha*a</td>
<td>Whole cereal plants</td>
</tr>
</tbody>
</table>

3. **COMBUSTION PROCESS**

The combustion process takes place several stages.

The biomass is transformed to water vapour, carbon dioxide (CO₂), nitrogen (NOₓ), carbon monoxide (to a small degree)(CO), hydrocarbons (to a small degree) (CₓHᵧ) und soot (to a small degree), in the various stages. Cinders, fine ash and coarse ash remain as residues.

The combustion process occurs in three phases.

The **first phase** is **drying** in which water vapour is almost exclusively released. The **second phase** is **pyrolysis** in which combustible gases such as hydrocarbons, carbon monoxide and hydrogen are released. The **third phase** is **oxidation** in which the gases formed during pyrolysis are combusted to form carbon dioxide and water.
Preparation material

Energy from biomass

In this regard, total combustion is characterised by making a high use of the fuels used and very low levels of emissions of carbon monoxide. In contrast, partial combustion is characterised by high emissions of combustible gases and a high carbon content in the ashes.

The main factors influencing the combustion process are primarily the calorific value, water content, oxygen supply and distribution, duration of the gases in the combustion chamber, combustion chamber temperature and combustion chamber form (adapted to the specific fuel).

Losses can exist because of radiation (depending upon construction, 3-7 %) and exhaust gas, (proportion of carbon dioxide in the exhaust gas and temperature relationship between the exhaust gas and air). A degree of effectiveness from 80 % (firewood boiler) to 95 % (automatic chip fuelling or pelletised fuelling) is related to the heating performance. In comparison, the degree of effectiveness of an open fire amounts to ca. 5%.

4. EMISSIONS

In association with the combustion of biomass, a range of undesirable emissions originate which, at maximum output, are over the limits set in the relevant legal regulations. The main area of attention has regard to the contents of carbon monoxide (CO) and nitrogen oxides (NO\textsubscript{x}). For example, in Germany, the following limits for wood and straw are applicable:

| Natural wood: | |
|---|---|---|---|---|---|
| Plant performance | CO (g/m\textsuperscript{3}) | Dust (mg/m\textsuperscript{3}) | Org. C (mg/m\textsuperscript{3}) | C | NO\textsubscript{x} (mg/m\textsuperscript{3}) |
| < 15 kW | Currently no limits |  |  |  |  |
| 15 - 50 kW | 4 | 150 | - | - | - |
| 50 - 150 kW | 2 | 150 | - | - | - |
| 150 - 500 kW | 1 | 150 | - | - | - |
| 500 - 1000 kW | 0,5 | 150 | - | - | - |
| 1000 - 5000 kW | 0,25 | 150 | 50 | 500 |  |
| 5000 - 50000 kW | 0,25 | 50 | 50 | 500 |  |

| Straw and similar materials: | |
|---|---|---|---|---|---|
| Plant performance | CO (g/m\textsuperscript{3}) | Dust (mg/m\textsuperscript{3}) | Org. C (mg/m\textsuperscript{3}) | C | NO\textsubscript{x} (mg/m\textsuperscript{3}) |
| < 15 kW |  |  |  |  |  |
| 15 - 100 kW | 4 | 150 | - | - | - |
| 100 - 5000 kW | 0,25 | 150 | 50 | 500 |  |
| 5000 - 50000 kW | 0,25 | 50 | 50 | 500 |  |
The emissions are largely dependent upon the combustion process i.e. the technology used, the fuels used, and operating management. To reduce dust emissions, additional dust removal procedures are installed. Various processes are available such as textile filters (high investment and operating costs – very good degree of effectiveness), electro-filters (high investment costs, good degree of effectiveness), cyclones (low investment and operating costs, lower degree of effectiveness) or multi-cyclonic systems (median costs, median degree of effectiveness).

5. COMBUSTION PLANTS
The spectrum of combustion plants is extremely varied. It ranges from simple tile stoves through to fully automatic wood chip or pelletised furnaces. Possible categorisation of the types of plant follows quite different criteria. In addition to plant size, these include the fuels used, the feeding systems or the furnace technology.

The following table provides a categorisation based upon plant size:

<table>
<thead>
<tr>
<th>Plant Category</th>
<th>Power Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Smallest plant</td>
<td>&lt; 15 kW</td>
</tr>
<tr>
<td>Small plant</td>
<td>15 kW - 500 kW</td>
</tr>
<tr>
<td>Middle sized plant</td>
<td>500 KW - 10 MW</td>
</tr>
<tr>
<td>Large plant</td>
<td>&gt; 10 MW</td>
</tr>
</tbody>
</table>

With regard to the feed system, a differentiation is made between plants which work on a continuous and discontinuous basis as well as automatic and manual feed systems.

Continuous feed automatic furnaces are differentiated base stoker furnaces and forced air furnaces.

With regard to the furnace technology, differentiation is made between
- **Base stoker furnaces**
- Sloping grate and reciprocating grate furnaces
- Fluidised bed combustion furnaces
- Pre-burner furnaces

Combustion plants for the utilisation of solid biomass as a fuel consist of the following plant components:

**Fuel storage with an extraction apparatus** (reciprocating feed/ moving floor, circular scraper)

**Fuel transfer from the fuel storage area to the furnace** (screw feed, conveyor, floor scraper, trough carriage, pneumatic carriage)
Transferring the fuel into the combustion chamber (screw drive, hydraulic punch or a discharge cyclone for the separation of carrier air/fuel)

Boiler (hot water boiler, steam boiler, air heater)

Air regulation with an oxygen sensor (primary air and secondary air system)

Flue gas cleaning (dust remover/cyclone, filter, denitrification).

Ash removal attachment.

In addition to these listed plant types for the combustion of biomass, there are also the plant technologies of pyrolysis and gasification. The differentiation between pyrolysis, gasification and combustion is achieved by means of controlling the oxygen supply. Pyrolysis occurs in the absence of oxygen, gasification with a hypostoichometric oxygen supply and combustion with an optimal oxygen supply. The oxygen supply is characterised by the symbol $\lambda$:

<table>
<thead>
<tr>
<th></th>
<th>$\lambda$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pyrolysis</td>
<td>$\lambda = 0$</td>
</tr>
<tr>
<td>Gasification</td>
<td>$0 &lt; \lambda &lt; 1$</td>
</tr>
<tr>
<td>Combustion</td>
<td>$\lambda &gt; 1$</td>
</tr>
</tbody>
</table>

Pyrolysis and gasification plants are not described in the script because these types of plants are still in the developmental stage.

6. AREAS OF USE

The thermal utilisation of biomass generally covers base load heat consumption because biomass boilers work most effectively in the base loading area. Peak loadings are catered for by the use of conventional boilers that can be put on line as required. Larger biomass furnaces are also built as thermal power plants. These thermal power plants replace conventional power plants.
Definition

Biogas originates from microbiological decomposition of organic substances that occurs under a lack of air. It is a combustible gas that consists of up to ca. 2/3 methane.

1. Choice of biomass

For the achievement of a good biogas yield, it is necessary to know the potential of the individual substrates (starter materials). This potential is determined from the composition of the raw materials i.e. through their proportions of carbohydrate, fat and protein. The biogas yield can be estimated from the composition of the individual starter materials.

<table>
<thead>
<tr>
<th>Substrate</th>
<th>Max. methane yield [Wt.%]</th>
<th>Max. methane yield [m³/t ODM]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carbohydrate</td>
<td>27</td>
<td>370</td>
</tr>
<tr>
<td>Fat</td>
<td>72</td>
<td>998</td>
</tr>
<tr>
<td>Protein</td>
<td>42</td>
<td>585</td>
</tr>
<tr>
<td>Plants</td>
<td>34</td>
<td>470</td>
</tr>
</tbody>
</table>

The theoretical maximum values presented in the table are not achieved in practice because it is not possible to achieve 100% decomposition of the organic substances.

For estimating the biogas potential of substrates, the proportion of energy-rich material fractions in the organic mass, the proportion of organic dry matter (ODM) within the total dry matter (DM), and the dry matter content of the substrate need to be taken into account. For the energy yield, the methane content of the biogas (alongside methane also carbon dioxide and water vapour), as well as the decomposition performance of the current biogas plant, are of additional importance.

So, for example, it can be calculated that, for an average plant derived substance with 90% ODM, 25 % DM content, a 60 % methane content in the biogas and 70 % decomposition performance in the biogas plant, an amount of 123 m³ of biogas arises per tonne of fresh substrate. If the decomposition performance of the biogas plant reduces to 50%, the associated gas yield reduces to 88 m³ of biogas / t of fresh substrate. Should a highly energy rich substrate with about a 50% proportion of fat, with 50% DM, 25% DM content, a 60% methane content in the biogas and a 70% decomposition performance level, the biogas yield can rise to ca. 200 m³ of biogas / t of fresh substrate.

For other materials, the following values can serve as standards where distinct yields have been demonstrated for partially digested materials (liquid manure, manure, sewage sludge).

The following table shows several typical gas-yields for various substrates. (ODM = organic dry matter)
<table>
<thead>
<tr>
<th>Substrate</th>
<th>Methane/t ODM (m³)</th>
<th>Biogas/m³ liquid (m³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cattle liquid manure</td>
<td>200</td>
<td>20</td>
</tr>
<tr>
<td>Pig liquid manure</td>
<td>300</td>
<td>30</td>
</tr>
<tr>
<td>Poultry manure</td>
<td>250</td>
<td>40</td>
</tr>
<tr>
<td>Sewage sludge</td>
<td>300</td>
<td>5</td>
</tr>
<tr>
<td>Biowaste</td>
<td>250</td>
<td>100</td>
</tr>
<tr>
<td>Old fat</td>
<td>720</td>
<td>650</td>
</tr>
<tr>
<td>Cut grass</td>
<td>480</td>
<td>125</td>
</tr>
</tbody>
</table>

2. **THE ORIGIN OF BIOGAS**

Biogas arises by means of a multi-staged process (fermentation or digestion) through the activity of anaerobic micro-organisms (i.e. with the exclusion of air or oxygen). Many varied strains of organisms take part in this process, the composition of which depends upon the prevailing specific process conditions (e.g. starter material for the fermentation, temperature, pH value etc.). Because the micro-organisms can be adapted to various substrates, almost every organic substance can be decomposed by fermentation.

Large molecular organic substances are decomposed in numerous stages into a few small sized molecular materials and finally through to methane. Alongside biogas that originates from fermentation there is a fermentation residue which consists of a mixture of water, non-reducible organic substances (mostly cellulose-rich or woody substances) as well as inorganic substances (sand, other soil components, salt, and other minerals). The fermentation takes place in a moist environment. The micro-organisms require a water content of at least 50% in the starter substrate.

The **first stage** is **hydrolysis**.

In this phase, large molecular organic substances are split up into smaller units by bacteria by the inclusion of water molecules at the point of splitting (hydrolysis). The splitting up of woody substances (lignin and cellulose) by micro-organisms is only possible with great difficulty. That is why wood overall is not suited to, or can only be decomposed extremely slowly by, fermentation.

The **second stage** is **acid formation**.

In this phase the small molecular units are decomposed into small molecular organic acids such as, for example, acetic acid, propionic acid, butyric acid and lactic acid, as well as alcohols (to a small degree), carbon dioxide (to a small degree) and hydrogen (to a small degree) by bacteria. The optimum temperature for acid formation lies at around 30 °C and the optimum pH at about 6. In the overall process, hydrogen build-up that is not led off has an inhibiting effect on the effectiveness of the acid formation phase.

The **third stage** is **acetic acid formation**.

In this phase, the small molecular organic acids and alcohols are decomposed into acetic acid, carbon dioxide and hydrogen by bacteria. An increased concentration of hydrogen also has an inhibiting effect on this process.
The fourth stage is methane formation. In this phase, acetic acid, carbon dioxide and hydrogen are converted to methane by bacteria. In relation to this, carbon dioxide is present in excess and remains as a residue in the gas mixture. Because of the varying groups of micro-organisms this results in two temperature optima for the process – as for many other biological processes as well – for the mesophilic area (ca. 35 °C) and the thermophilic area (ca. 55 °C). The pH optimum lies at about pH 7. Hence, continuous use of the intermediary products is essential to prevent acidification of the process from occurring.

3. BIOGAS COMPOSITION
Biogas has approximately the following composition.

<table>
<thead>
<tr>
<th>Component</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Methane</td>
<td>40-75 %</td>
</tr>
<tr>
<td>Carbon dioxide</td>
<td>25-55 %</td>
</tr>
<tr>
<td>Steam</td>
<td>0-10 %</td>
</tr>
<tr>
<td>Nitrogen</td>
<td>0-5 %</td>
</tr>
<tr>
<td>Oxygen</td>
<td>0-2 %</td>
</tr>
<tr>
<td>Hydrogen</td>
<td>0-1 %</td>
</tr>
<tr>
<td>Ammonia</td>
<td>0-1 %</td>
</tr>
<tr>
<td>Hydrogen sulphide</td>
<td>0-1 %</td>
</tr>
</tbody>
</table>

In the above table, the values shown are reference values. The true values can deviate from the values shown in the table depending upon the substrates used.

4. BIOGAS CHARACTERISTICS
Biogas has approximately the following characteristics which also can deviate in a similar way depending upon the substrate used.

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Density</td>
<td>1,2 kg/m³</td>
</tr>
<tr>
<td>Calorific value</td>
<td>4-7,5 kWh/m³ (depending on methane content)</td>
</tr>
<tr>
<td>Ignition temperature</td>
<td>700 °C</td>
</tr>
<tr>
<td>Ignition concentration gas content</td>
<td>6-12 %</td>
</tr>
<tr>
<td>Smell</td>
<td>Rotten eggs (WARNING: de-sulphurised biogas is barely perceptible)</td>
</tr>
</tbody>
</table>

5. BIOGAS PLANTS
In comparison to other plants for using of renewable energy, a multitude of systems and processes exist for biogas plants and these are classified according to various criteria. The selection of any particular system is always decided on an individual basis and is dependent upon various factors. In the following table the most useful classifications are quoted:
<table>
<thead>
<tr>
<th>Criterion</th>
<th>System</th>
<th>Characteristics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dry matter content</td>
<td>Wet fermentation</td>
<td>Up to ca. 15 % DM content</td>
</tr>
<tr>
<td></td>
<td>Dry fermentation</td>
<td>From 25-35 % DM content</td>
</tr>
<tr>
<td>Temperature level</td>
<td>Psychrophilic</td>
<td>Up to 20 °C</td>
</tr>
<tr>
<td></td>
<td>Mesophilic</td>
<td>35 °C</td>
</tr>
<tr>
<td></td>
<td>Thermophilic</td>
<td>55 °C</td>
</tr>
<tr>
<td>Staging</td>
<td>Single stage</td>
<td>All decomposition stages at the same time alongside each other</td>
</tr>
<tr>
<td></td>
<td>Two stage</td>
<td>Separation of hydrolysis and methane formation</td>
</tr>
<tr>
<td></td>
<td>Multi-stage</td>
<td>Separation of hydrolysis, acid formation and methane formation</td>
</tr>
<tr>
<td>Charging</td>
<td>Continuous</td>
<td>The same quantity of substrate added and removed daily</td>
</tr>
<tr>
<td></td>
<td>Batch operation</td>
<td>Complete filling and complete emptying. Change-out receptacle necessary</td>
</tr>
<tr>
<td>Fermenter form</td>
<td>Fermentation channel</td>
<td>Long, rectangular, concrete</td>
</tr>
<tr>
<td></td>
<td>Horizontal tank</td>
<td>Steel receptacle e.g. used oil storage tank</td>
</tr>
<tr>
<td></td>
<td>Vertical circular receptacle</td>
<td>Silo made of concrete or steel</td>
</tr>
<tr>
<td>Mixing</td>
<td>Mechanical</td>
<td>Slow moving central agitator</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Rapid moving side located agitator</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Paddle agitator (for horizontal fermenters)</td>
</tr>
<tr>
<td></td>
<td>Hydraulic</td>
<td>External pump</td>
</tr>
<tr>
<td></td>
<td>Pneumatic</td>
<td>Injection of biogas</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Utilisation of the gas pressure for production of a hydraulic gradient</td>
</tr>
<tr>
<td>Substrates</td>
<td>Agricultural plants</td>
<td>Liquid manure, manure, cut green material</td>
</tr>
<tr>
<td></td>
<td>Co-fermentation plants</td>
<td>Liquid manure, manure, cut green material + certain waste materials (e.g. fat)</td>
</tr>
<tr>
<td></td>
<td>Industrial plants</td>
<td>Only certain waste materials (e.g. the &quot;green waste bin&quot;)</td>
</tr>
</tbody>
</table>
A biogas plant requires daily attention and monitoring because it a matter of a biological process which is not totally insensitive. Biogas plants have been operated for ca. 80 years, primarily in agriculture in the beginning. The central component of a biogas plant is the reactor or fermenter along with its attachments. Concrete or steel (enamelled, coated or stainless steel) is used as a construction material. The reactor is insulated and fitted out with heating (external heat exchanger, heating coils on the inner wall or under-floor heating). Because fermentation usually lasts for more than three weeks, and this can lead to separation of the mixture, (floating layers and sinking layers) care should be taken to regularly agitate the substrate.

Alongside the reactor and its fittings, a intermediary storage unit is needed for putrified substrate which cannot be directly recycled. Pumps for charging and emptying the reactor, a preparation unit possibly with a macerator, pre-mixer, quantity buffer, sorting out of disruptive materials or making hygienic, a gas line with a meter, condensate separation, desulphurisation, safety technology and storage unit as well as often a block heat power generation unit (BHKW) for the production of electricity and heat from biogas, all form part of a biogas plant.

6. USE AREAS
Biogas is mostly used today as a combustible gas for gas motors that produce electrical energy by means of a generator as well as utilisable heat at a temperature level of ca. 80-90 °C. The economic viability of a biogas plant often stands or falls upon the utilisation of the waste heat by-product.
Of the total quantity of electrical energy produced, generally 20-40% is used for driving the plant itself (pumps, agitators, macerators, etc.).
Of the total quantity of heat produced, about 30-50% is used for heating the fermenter. The larger the plant, the smaller the respective proportion of consumed by the process.
Biogas technology is also used in order to reduce the freight component associated with organic substances e.g. in waste-water treatment or for pre-treatment before placing waste in tips.
The use of biogas purely for water heating (heating, stove) is only of secondary importance.