Some Notes on Energy Efficiency

Short version of the seminar on energy and energy efficiency by Dr. Thomas Bürki

Contents:

1. Why Energy in Cleaner Production?

Cleaner production (CP) means ***the continuous application of an integrated preventive environmental strategy applied to processes, products and services to increase efficiency and reduce risks to humans and the environment***. In simple words one could say: less pollution of the environment while producing a good through realising a continuous improvement at all stages of the firm.

Pollution normally is regarded to be obvious when coming from a (toxic) mass flux, but not so obvious, when resulting from energy consumption. Any energy consumption is related with an impact to the environment. An issue of growing importance is GHG emissions when using (fossil) energy.

2. What is the relevance of energy?

Use of end energy is connected with primary energy use and with environmental pollution - from extraction of the raw material until the final consumption:

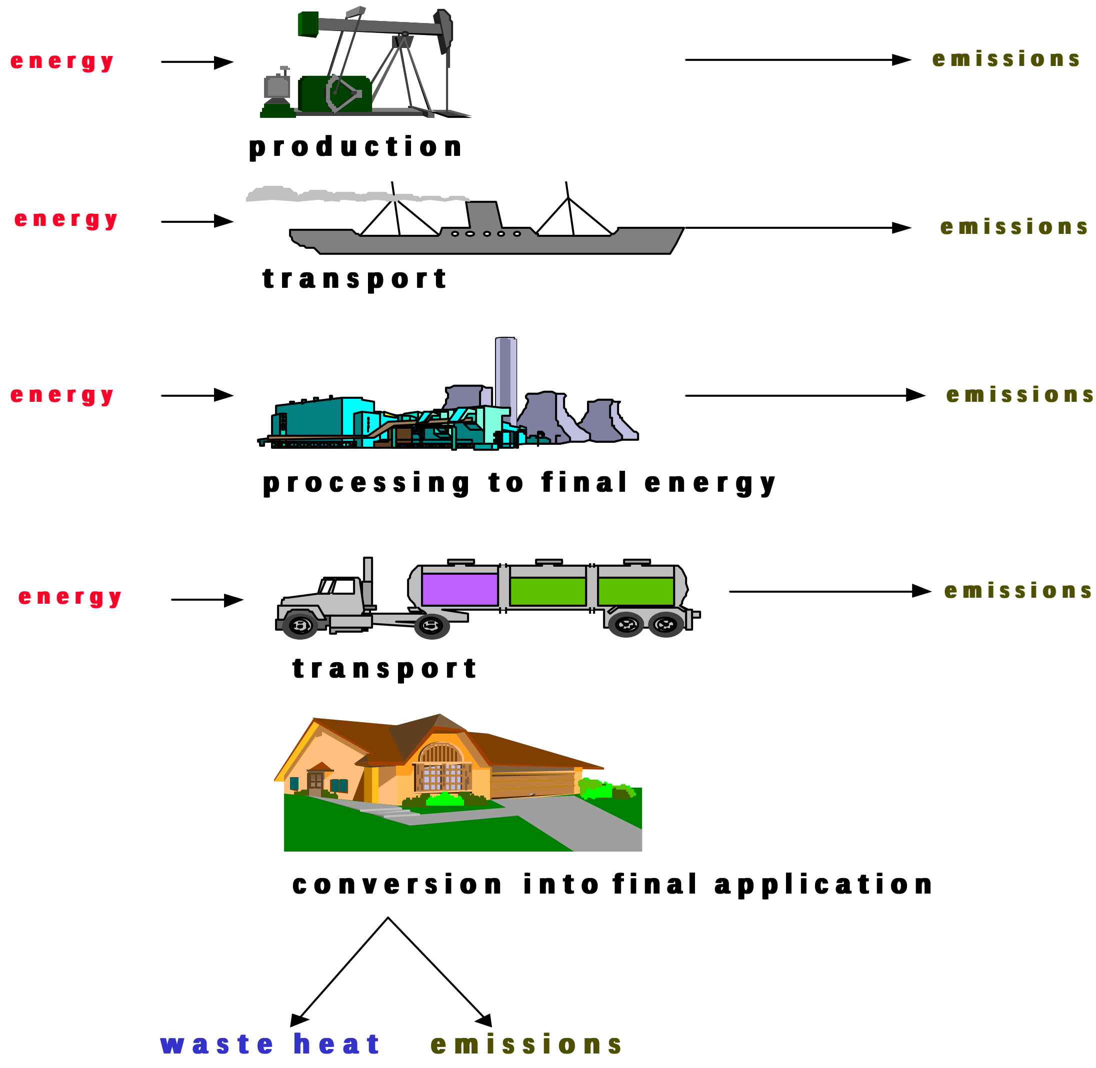

Figure 1: the history of energy

Regarding the overall pollution of an industrial company, the most important contribution to pollution is normally the use of energy:

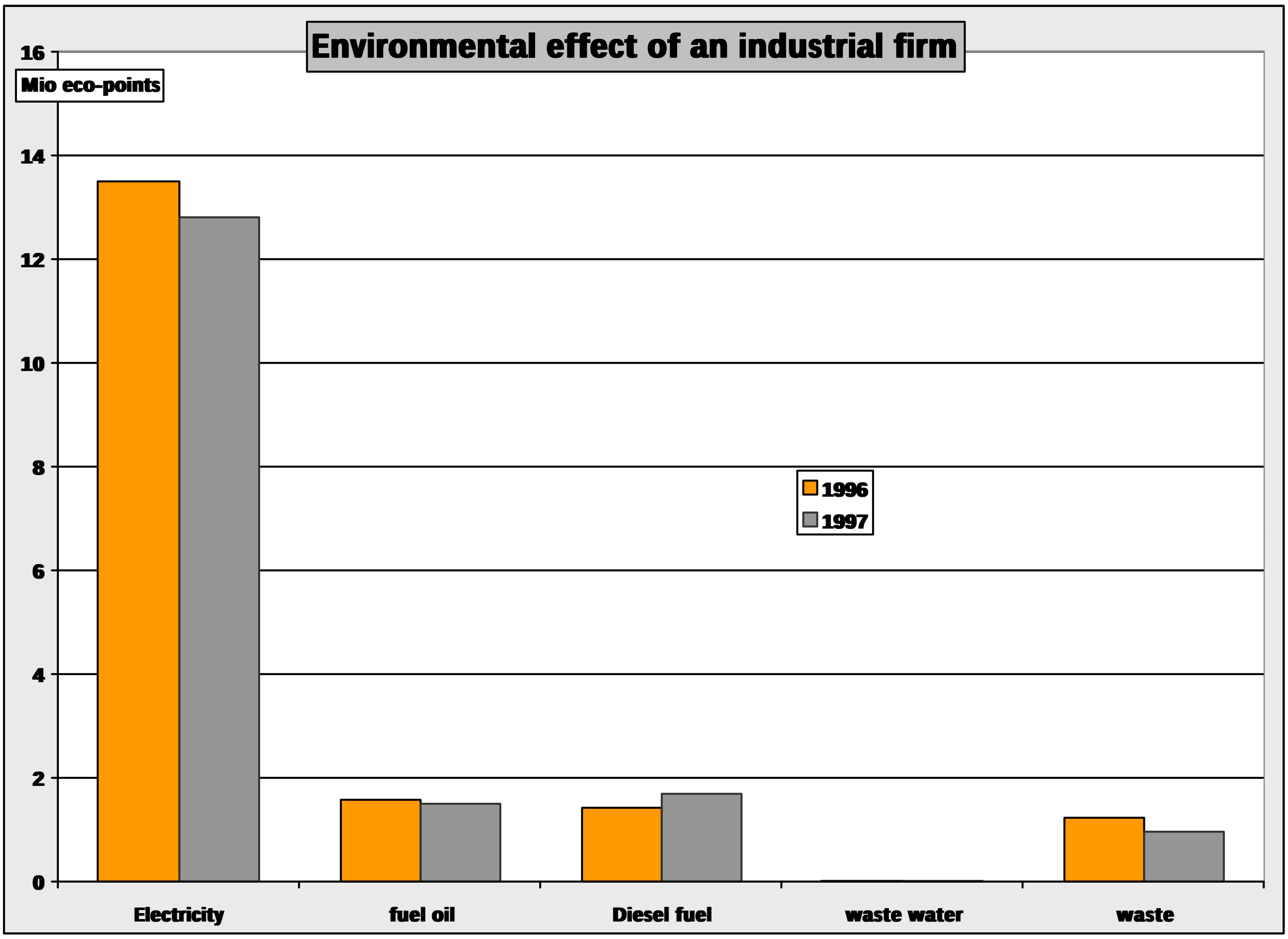

Figure 2: Environmental effect of an industrial firm

Therefore, reducing the energy consumption is an important contribution to CP.

3. Environmental effects of energy use

The environment is affected by using energy. The affected compartment is above all the air (besides water and soil). Emissions cause local and global problems.

Burning coal, fuel oil, and gases:

The exhaust gas consists of

CO, particulate matter (PM), NO_x, SO_2, → Local problem

CO_2. CH_4 → Global problem

"direct poison"	cancer	"slow poisons" (lungs etc.)	pollutant to plants	GHG climate
CO	PM	NO_x (SO_2)	SO_2 (NO_x)	CO_2 CH_4
incomplete combustion		± inevitable. Reaction between N+O from the air. Can be influenced	Inevitable. Depends on S-content of fuel	Inevitable. Depends on C-content of fuel

3.1.1 Rough estimation of emissions at plant (burning of fossil fuel):

a) Fuel Oil (light oil ('Diesel oil'), heavy oil ('bunker')

Emission	*Amount*	*Unit*
NO_x	(120) ... 250 ... >500	$mg/kWh_{fuel\ oil}$
SO_2	340 (0.2% S) 1700 (1% S)	$mg/kWh_{fuel\ oil}$
CO_2	270 - 280	$g/kWh_{fuel\ oil/bunker}$

b) Natural Gas

Emission	*Amount*	*Unit*
NO_x	(80) ... 200 ... >400	mg/kWh_{gas}
SO_2	≈ 0	mg/kWh_{gas}
CO_2	200	g/kWh_{gas}

c) Electricity (coal fired power plant)

Emission	*Amount*	*Unit*
NO_x	~ 600	mg/kWh_{el}
SO_2	~ 16	g/kWh_{el}
CO_2	2000	g/kWh_{el}

Reducing the pollution from industrial production therefore means: use less energy while carrying our the same (or improved) industrial process, in other words: raising energy efficiency and (GHG-emissions!) fuels witch, means change to fuels with less C-content (coal → fuel oils → gases) or renewable energies. Raising the energy efficiency is moreover a valuable way to combine less pollution with more profit to the enterprise.

4. Energy efficiency in the Industry

4.1 What is Energy Efficiency?

In the ideal case ***energy efficiency*** is defined as the amount of energy consumed to produce one production unit. The unit of 'energy efficiency' is then e.g. kWh/ton, kWh/m^3, kWh/piece etc. To be precisely we should name this kind of indicator ***specific energy consumption***. It is the reciprocal value of energy efficiency.

Often, this value is very difficult or not at all to define, because the reference value can not or only hardly be defined. Example: factory, that produces different machines or various goods: what figure do you apply the consumed energy to?

Therefore energy efficiency can be defined in an other way. We say, (technical) energy efficiency can only be risen, when respective measures have been realised. So energy efficiency it is the quotient between the hypothetical energy consumption (i.e. energy that would have been consumed if no measures had been realised) and the effective energy consumption.

Energy efficiency in the year x:

$$Eeff_X = \frac{EC_X + ESacc_{until\ x}}{EC_X} \bullet 100$$

With:

EC_x = total energy consumed in the year X

$ESacc_{until\ X}$ = accumulated energy savings through realised measures from the basic year until the year X

$Eeff_X$ = Energy efficiency in the year X in %

total energy consumption is the addition of the different forms of energy. To integrate the overall impact to the environment of the respective form of energy, this addition can be done as follows (European context, situation in Columbia <u>might</u> differ)

$EC = E_{fossil} + 2*E_{electric} + 0.1*E_{renewable}$

To calculate the energy efficiency, we need the list of all realised measures. This list contents the respective measures, the amount of energy saved, the amount of emissions reduced. Additionally, we have to account the energy consumed of the company in the same period.

The accumulated energy savings are the result of the enterprise's work (realised measures) from the reference year to the actual year.

The list of realised measures is therefore the central means of the success control. It allows on the one hand to observe the activities of the company. On the other hand, the company has a valuable means in the energy management to confirm the rentability of the measures realised: we know the cost of every measure and therefore the pay back period and other project related information. We can easily calculate the relevant economic indices so to say as a by-product of the controlling of the development of the energy efficiency. Finally, when financial values are taken up in the list, the real economy of measures can be 'precisely' calculated. Thus it is a feed back to the (energy) management of the company and delivers specific financial values (e.g. pay back period or similar) that can be looked at to decide whether a measure (and consequently the respective emissions reduction of CO_2 or other GHG) is additional or not.

4.2 How Can Energy Efficiency Be Improved?

Improving the energy efficiency means reducing the amount of energy used to run a process in an (industrial) process/company i.e. to produce a good.

This implicates, that one has to understand the process to be improved. The first step is therefore to define the process: limits, steps included, parameters, expected output of the process etc.

"Process" does not always mean the whole production process in an enterprise. It can also be a infrastructural process (production of cold water, compressed air, heat/steam but also drying, transportation in the factory etc.). The analysed 'process' can be one or several parts of a whole/bigger process:

- filling of bottles in a beverage production company
- electric motor of injection machines in a plastic production plant
- disintegrate raw material in a paper mill
- etc.

With all these processes or process steps we must know what is happening: we must explore the process. The elaboration of a program to improve energy efficiency starts therefore with analysing the process and discussing it with the responsible persons.

4.3 How Do We Analyse a Process/Industry?

4.3.1 How to Find the Relevant Processes?

When analysing an enterprise it is important get a general idea of the whole site. Therefore one has to make a (at least a mini) audit of the site:

- Walkthrough
- Check documentation, equipment etc.
- Take out invoice based information (electricity, fuels, coal)
- Consumption patterns:
  installed power capacity, operating times
  daily, monthly, annual amounts of consumed energy
  demand profile, peaks

To make "visible" what happens in the factory: evaluate the data in charts, calculate performance parameters, energy flows etc.

In most cases, measurements are necessary. This does not mean that extensive measuring campaigns have to be carried out. Mostly simple measurements (as an enrichment of the in other ways collected data) produce very useful and sufficient information. Anyway it is important to make a measurement conception (and we must know exactly how to evaluate the measured data!) before starting:

- Goal of the measurement: what information do you want to get?
- What results are expected?
- Data necessary to get to the message
- Required accuracy

Then choose the equipment and decide the points of data collection.

When evaluating the measured data start looking for irregularities or abnormalities. They are the alarming signs ("the cries of the process") and lead you quickly to better knowledge on what is happening/what is going wrong.

The following diagram shows the development of the peak load in a production site as a first impression on the consumption of electricity – and on how the plant is managed.

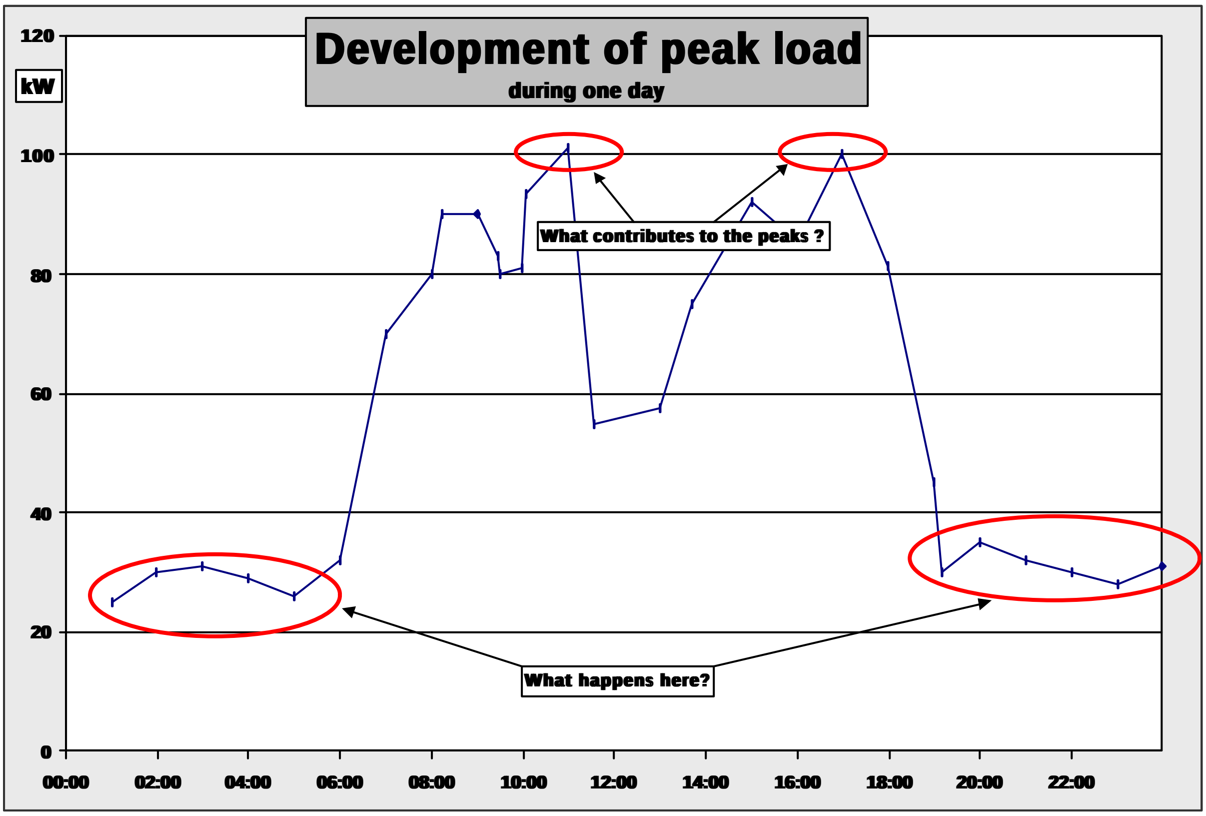

Figure 3: development of the peak load

Here, the "abnormalities" are: 2 strong peaks (at approx. 11:00 and 17:00 hrs) and a relatively high consumption during the night.

1. Peaks cost money. Therefore they must be reduced ⇒ which consumers are active at 11:00 and 17:00 hrs? Can one or several of them be advanced or postponed?
2. Investigate and reduce consumption during night time ⇒ must these installations be operated? What for? Etc.

From the walkthrough, the discussion with the relevant people of the plant, the data from documentation or from the installations you get an idea on which are the most important consumers; these are machines with a big power consumers or with long operating times.

4.3.2 Analyse the processes

The golden rule to analyse the energy consumption of a process or a machine is:

- 1st step: analysis of the needs
- 2nd step: analysis of the distribution
- 3rd step: analysis of the production of energy

The detailled analysis can be done according to the following pattern:

a) Define the process and understand what is happening in the process

b) sketch the process structure and an energy flowchart: simple, but complete (‘block diagram’)

c) recognise the interdependence between process/process steps and energy consumption

d) analyse the distribution of the final energy consumed

e) analyse which possible modification in the process leads to what reduction of energy consumption

f) analyse the production of the energy consumed

g) list up realistic measures with all relevant (incl. financial) information

h) make a clear recommendation on how and when to realise the measures

4.3.3 Examples

a) Why Do We Need an A/C Installation?

What is it used for?

- to remove heat from the room?
- to remove dust?
- to control humidity?
- else?

⇒ what is/are the relevant controlling parameter(s)? Is it/are they measured? Is it/are they connected with the process control?

b) Sketch a Block Diagram of the Process and a Simple and Complete Energy Flowchart

Example: plastic manufacturing process.

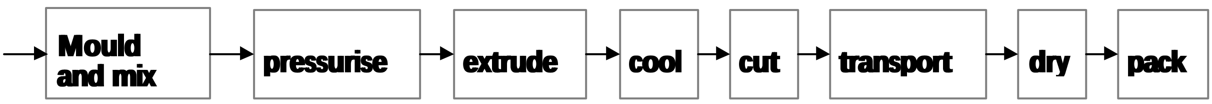

Figure 4: Block diagram of a plastic production process

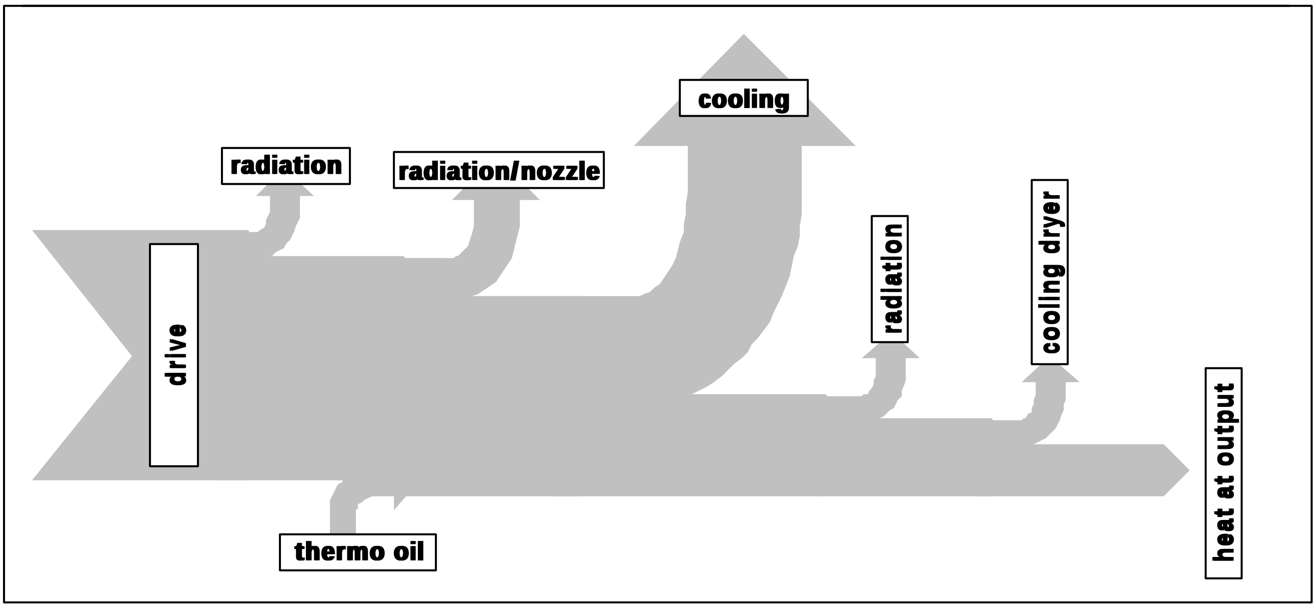

Figure 5: energy flow chart of a plastic production process

c) Recognise Interdependencies

What process parameter can be changed and which influence have these changes on the energy consumption?

- Has a modification of the production speed an influence on the energy consumption? Which?
- If compressed air is needed: does it have to be dried/cooled? What pressure level (compressed air) is necessary?
- Has the produced material (e.g. plastic raw material) to be dried to that value? What happens if not?
- Is there a connection between quality and energy consumption? Which one?
- Can the material be exchanged for another one consuming less energy? Can the design of the produced part be changed?

d) Analysis of the Distribution of Energy

Examples:

- look for leaks in the mains of pressurised air.
- look for poor isolation of cold/heat pipes
- electricity: the higher the voltage, the lower the current. Low current → low losses (~ square of tension!)

i) analyse the production of the needed form of energy

Example:

Refrigerating machine (chiller). In a factory cold water is needed. It is produced in a refrigerator. Does it run at an optimum?

In the refrigerator the following process runs off:

1. the gaseous refrigerant ("gas") enters the compressor at low pressure and low temperature
2. the compressor compresses the gas to a high pressure. At the outlet of the compressor, the gas is therefore at high temperature.

3. The hot gas is cooled down at constant pressure to the condensation temperature. Condensation temperature and condensation pressure are directly linked together
4. The gas is condensed at constant temperature and pressure: it is liquefied
5. The liquid refrigerant is throttled to low pressure. Therefore, the temperature is lowered as well. At the same time, the refrigerant is partially gasified.
6. In the evaporator the refrigerant gets totally gasified (at low temperature and pressure; temperature and pressure are constant during evaporation).
7. At low temperature and pressure it enters the compressor and the cycle starts again → step 1.

The refrigerating machine therefore consists of the following main parts:

1. compressor
2. heat exchanger 1 to cool the gas to the condensation point.
3. condenser to condense the refrigerant (= heat exchanger 2). Often heat exchanger 1 and 2 are the same unit, i.e. cooling and condensation run off in the same heat aggregate
4. throttle
5. evaporator (= heat exchanger 3)

The following energy flows are connected with the refrigerator:

1. electricity is needed to drive the compressor
2. heat exchanger 1: transfers heat from the gas to water (= secondary medium). High temperature are achieved in the secondary medium: heat is taken from the refrigerant
3. heat exchanger 2: transfers condensation heat to water. Medium temperatures are achieved. Heat is taken from the refrigerant.
4. heat exchanger 3: heat transfer from water, air etc. to the refrigerant to evaporate it. Heat is fed to the refrigerant

To the user heat exchanger 3 (evaporator) is the interesting part, because it transfers heat from the water (it gets cooled) to the refrigerant (it gets evaporated). The rest of the process runs off to enable the refrigerant to take over heat from the cooling water i.e. to cool it down.

The assembling of these components to a refrigeration machine is sketched in figure 6. For simplification, a machine is sketched, that uses only one heat exchanger (= condenser) instead of exchangers 1 and 2.

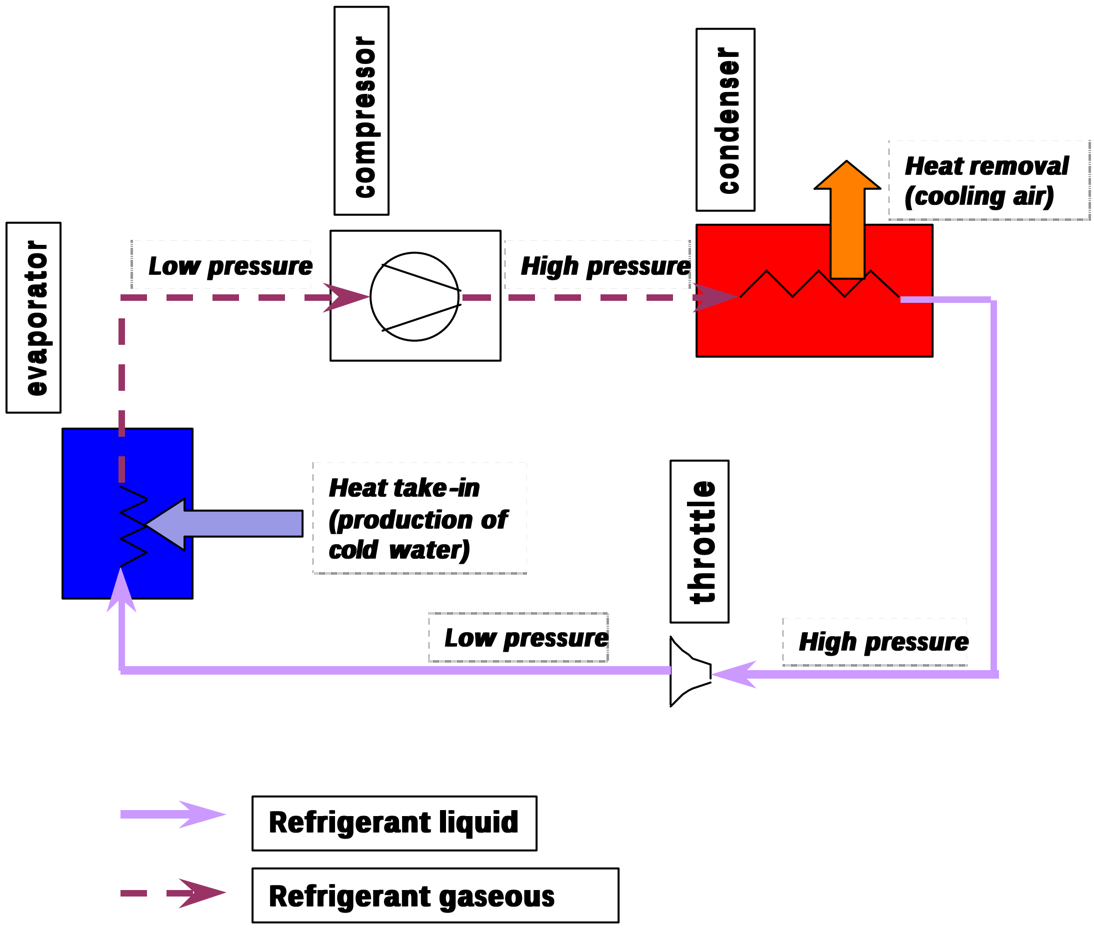

Figure 6: sketch of a refrigeration machine

The consumption of electric energy of the refrigeration machine depends mainly on two factors:

- the pressure difference between evaporation pressure and condensation pressure
- the quality (efficiency) of the compressor. With an existing refrigerating machine the electricity consumption can only be reduced by decreasing the difference between the pressure of condensation and evaporation.

The condensation pressure depends from the temperature of the medium the refrigerant is cooled and condensed with (normally ambient air). The evaporation temperature depends on the temperature the water has to cooled to.

j) list of possible measures

The energy flow chart is a good starting point to decide, where improvements can be made. The flow chart shows all the losses in the process.

Improvement means to reduce or prevent losses and to reduce the consumption of energy of the process. Possible solutions to prevent or to reduce heat losses are:

- Insulation of parts of the machinery (less radiation losses)
- Installation of a heat recovery system. It is a heat exchanger that preheats air, water etc. by cooling down the waste air, waste water etc. (reduction of waste heat)
- reduce leaks (e.g. leak detection and repair in a compressed air piping system)

Energy consumption can be reduced by:

- optimising operation parameters of machines (e.g. operating time, operation pressure)
- optimising process parameters (e.g. temperature of cold water)
- good maintenance (e.g. clean filters of a air compressor)
- etc.

4.3.3.1 Example 1: reduction of heat losses:

The easiest way to detect unnecessary losses (in distribution and elsewhere) is to analyse and interpret the energy flowchart. All **flows** of energy are basically **losses**, all **cycles** of energy indicate, that measures to improve the energy efficiency (**recovery**) have been realised. Regarding the energy flowchart, we start analysing where big amounts of energy are used or lost. Then we analyse step by step the whole process and describe potential improvement measures.

After the installation of an insulation and a heat recovery system the waste flow is partially changed into a circle. The new flow chart shows it:

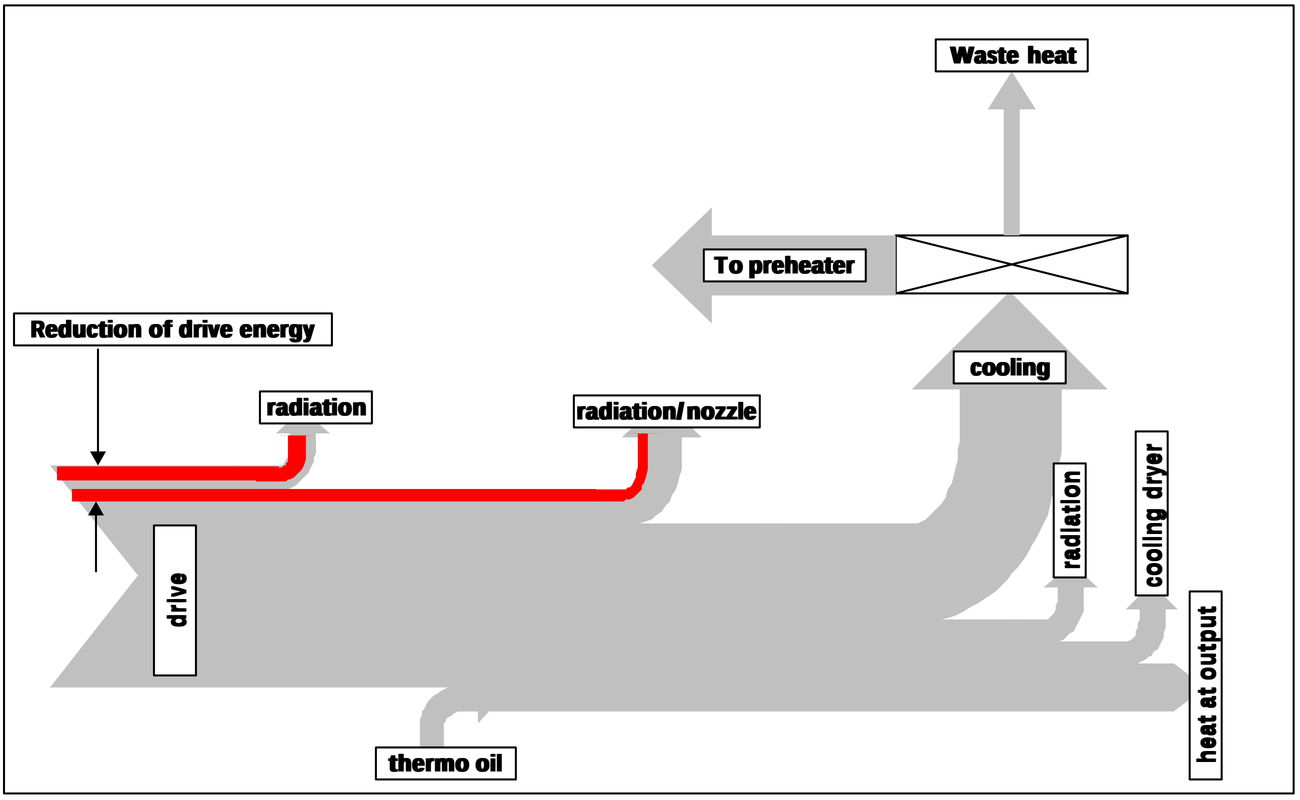

Figure 6: energy flow chart with insulation and heat recovery

4.3.3.2 Example 2: reduction of leaks of compressed air

To judge leaks in a system of compressed air, measurements are indispensable. The following chart shows, how leaks in the piping of compressed air can be determined.

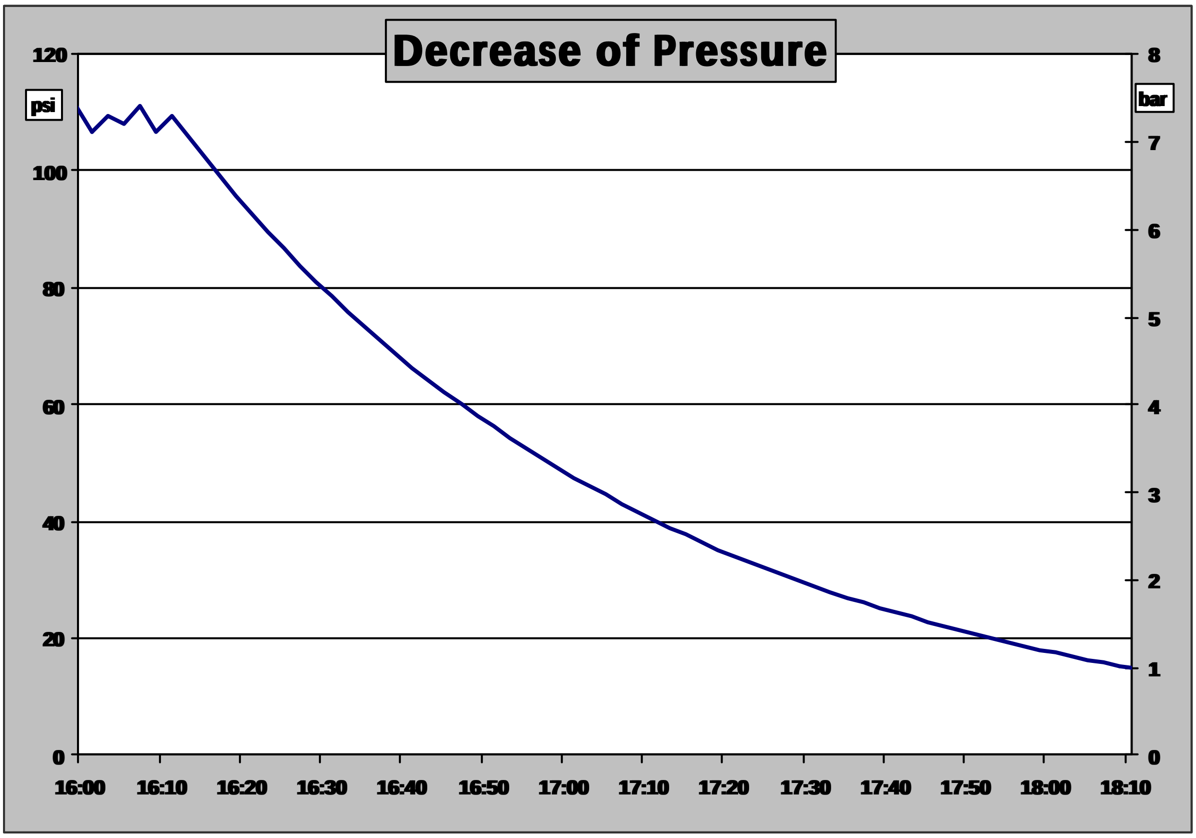

Figure 7: decrease of pressure in a compressed air piping system after compressor shut down and zero air consumption.

The leak can easily be calculated:

You know the content of compressed air in the system. Division by time ⇒ amount of air leaking

- To fill up the system the compressor needs a certain amount of electricity (measure or calculate). This amount of electricity is lost every two hours (see figure 5: system is emptied within 2 hrs).

You can determine the losses in a second way (or check the above value): You measure the electricity consumption of the compressor at zero use of compressed air:

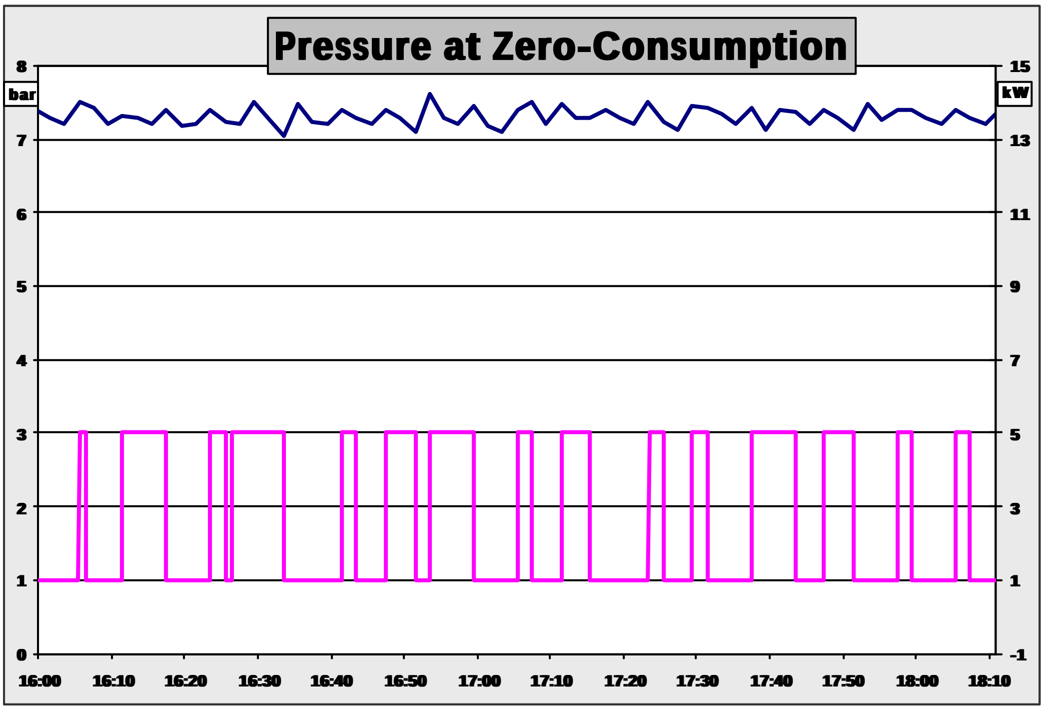

Figure 8: electricity needed to maintain the pressure of compressed air at zero consumption

4.3.3.3 Example 3: changes in the process

Changes of process parameters can lead to improvements in energy consumption. With the production of compressed air the level of pressure influences the electricity consumption severely. Therefore this level has to be questioned. If the actual pressure is at 120 psi:

- Why that level?
- Which consumer needs that level, why? What happens with less pressure?

The characteristics of an air compressor looks typically as follows:

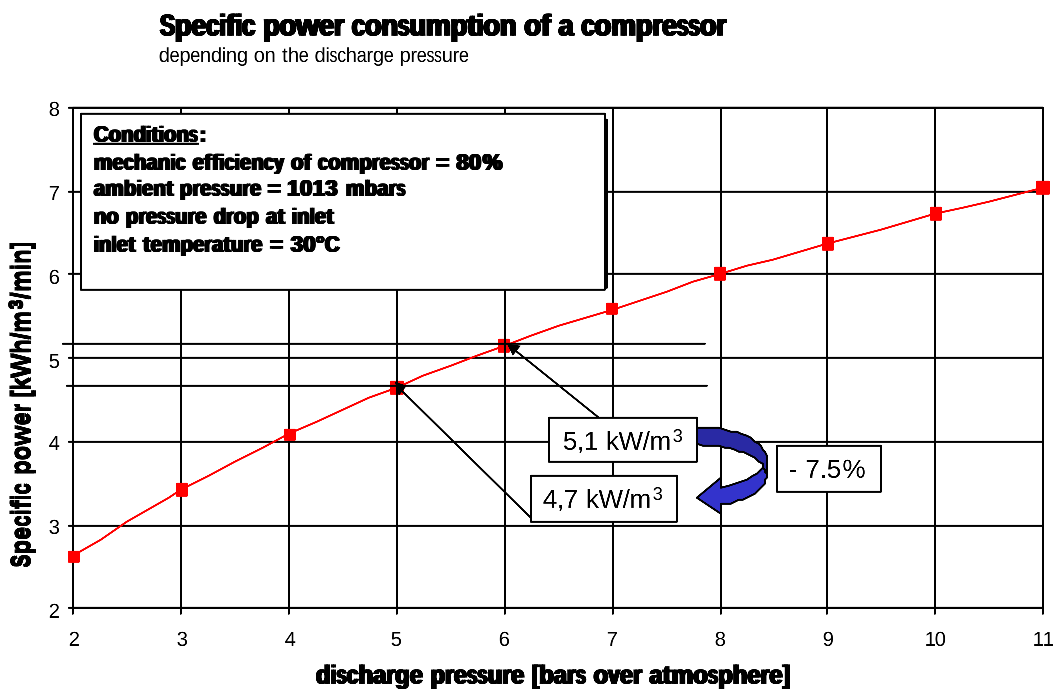

Figure 9: characteristic of an air compressor

If a pressure reduction by 15 psi can be reached, about 5 – 8% electricity are economised.

4.3.3.4 Example 4: good maintenance saves energy

Air compressors always have filters to clean the air before compression. It is normal that these filters get dirty. Dirty filters give a higher resistance to the air flow; in other words: the compressor has to make a higher pressure difference, which needs more electricity. But the benefit (amount of air at a certain pressure) is the same, i.e. the efficiency to produce compressed air is worse.

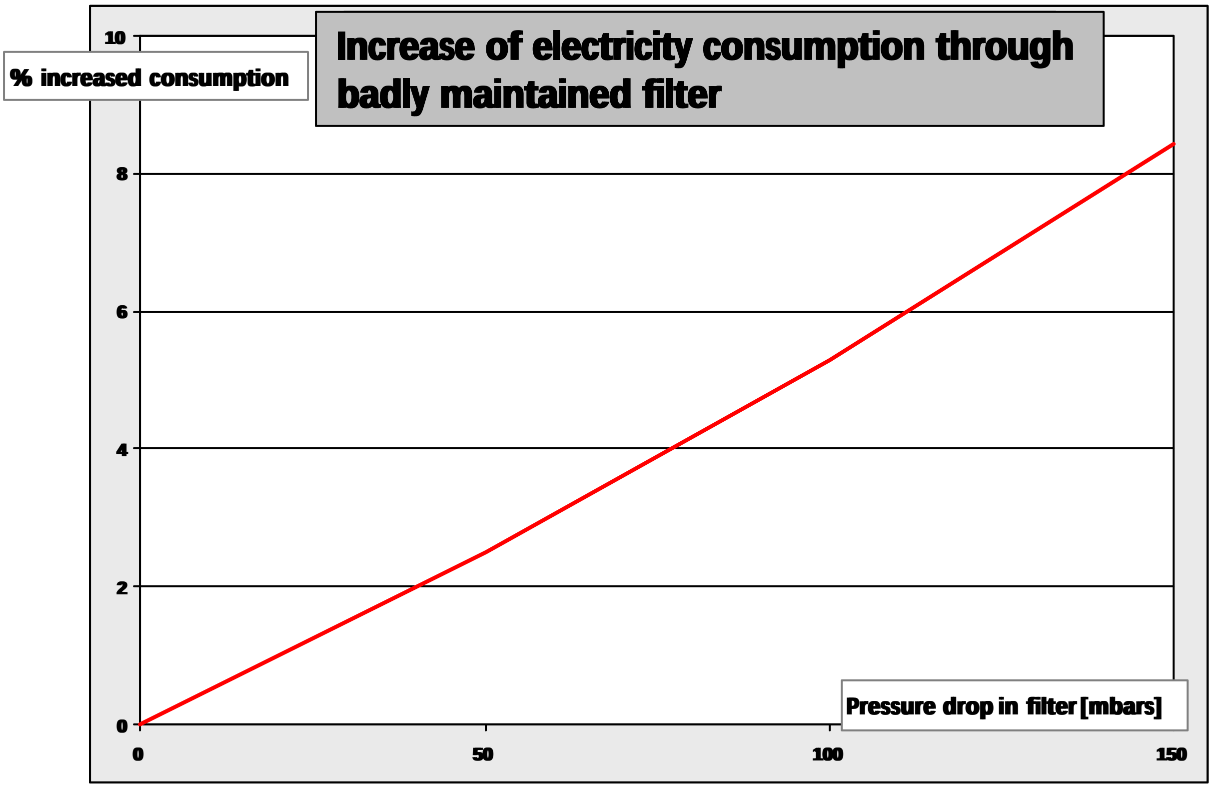

Figure 10: pressure drop in a bad maintained filter

i) make a clear recommendation to realise the measures

After the analysis it is very important to make a clear and understandable proposal to the management.

This proposal contains:

- actual state of the plant/process
- weak points (losses, small efficiencies etc.)
- possible improvement measures
- cost (investment, operation)
- profit by realised measure (reduction of energy consumption, reduction of energy cost, further profits)
- proposal how and when to install the measure (also order of realisation)

Attention: be careful when calculating the energy savings! If several measures are proposed, you normally can't simply add the benefit of the different measures.

4.3.3.5 Example 5: improvement with a coal fired boiler

A coal fired boiler is analysed. In the analysis you find three measures: one decreases the steam consumption by 15%, the second reduces the losses of the piping by 10%, and the third improves the boiler efficiency by 13%. Then the overall savings are not 15% + 10% + 13% = 38%. Why?

The measures cannot be equally weighed and they are not independent, but connected in series. This is shown in the following figure.

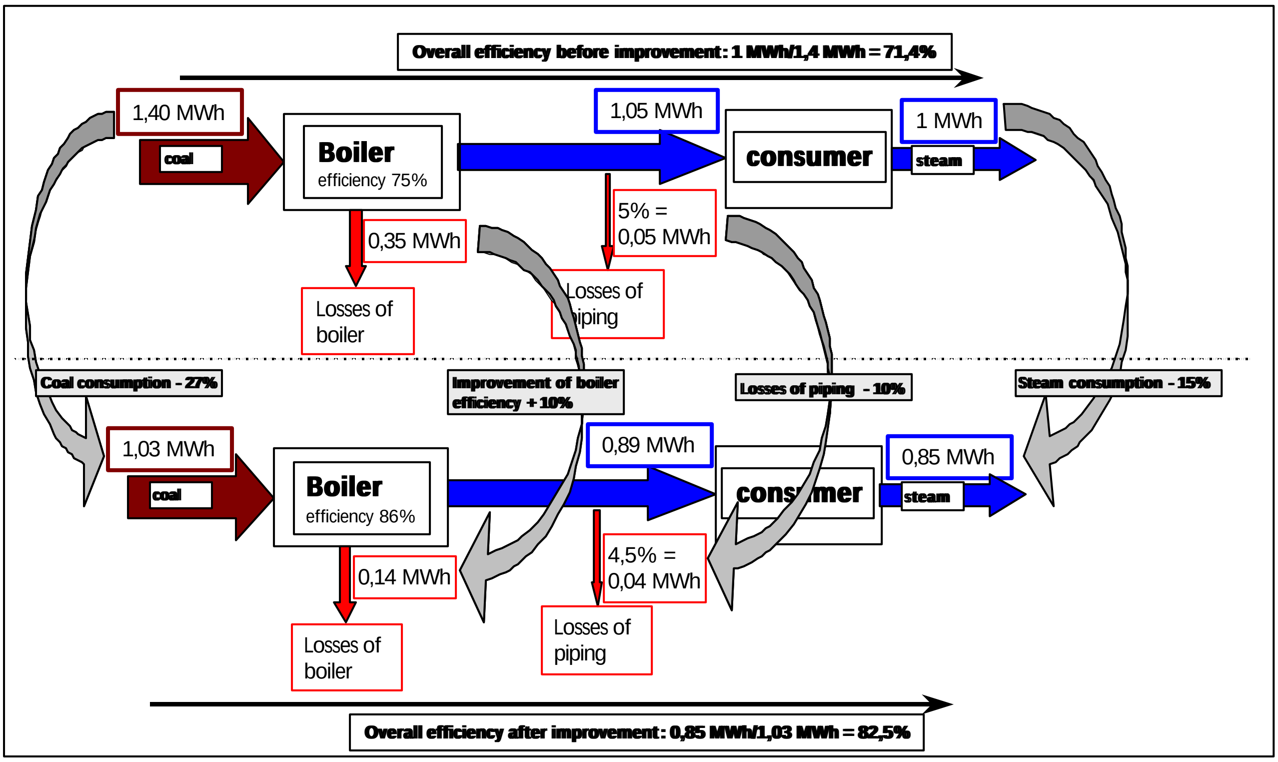

Figure 9: improvement of a coal fired boiler

Therefore the overall savings are approximately 16 %.