MOTOR CHALLENGE

Energy Efficient Motor Driven Systems

...can save Europe 200 billion kWh of electricity consumption and 100 million tonne of greenhouse gas emissions a year

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April 2004

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The Motor Challenge Programme

The Motor Challenge Programme is a voluntary programme promoted by the European Commission to help companies improve the energy efficiency of their electric motor driven systems. The Challenge focuses on electric drives, compressed air, fan and pump systems, for which it has been demonstrated that there exists a large technical and economic potential for energy savings.

Any organisations wishing to contribute to the Motor Challenge Programme objectives can participate. Companies that use motor driven systems can request Partner status. Organisations (in particular companies that supply motor driven systems and components) wishing to assist the Commission and Member States in carrying out the Motor Challenge Programme may become Endorsers.

More information can be found at http://energyefficiency.jrc.cec.eu.int

Definitions:

Billion	10^9, or a thousand million
kW	kilowatt
kWh	kilowatthour
MW	megawatt, equal to 1 000 kW
MWh	megawatthour, equal to 1 000 kWh
GW	gigawatt, equal to 1 000 000 kW
GWh	gigawatthour, equal to 1 000 000 kWh
TW	terawatt, equal to 1 000 000 000 kW
TWh	terawatthour, equal to 1 000 000 000 kWh

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Executive Summary

Switching to energy efficient motor driven systems can save Europe up to 202 billion kWh in electricity consumption, equivalent to a reduction of €10 billion per year in operating costs for industry. It would also create the following additional benefits:

- a saving of €5-10 billion per year in operating costs for European industry through reduced maintenance and improved operations (EU-25).
- a saving of €6 billion per year for Europe in reduced environmental costs (EU-25, calculated using the EU-15 fuel mix).
- a reduction of 79 million tonne of CO_2 emissions (EU-15), or approximately a quarter of the EU's Kyoto target. This is the annual amount of CO_2 that a forest the size of Finland transforms into oxygen. If industry is allowed to trade these emission reductions based on energy saved, this would generate a revenue stream of €2 billion per year. For EU-25, the reduction potential is 100 million tonne.
- a 45 GW reduction in the need for new power plant capacity over the next 20 years (EU-25).
- a 6% reduction in Europe's energy imports (EU-25).

To achieve this a four-year package of measures is suggested, investing €400 million in the motor systems market. The Motor Challenge Programme should continue to be the forum for developing common tools and fast learning, and ensure that the national programmes are implemented and achieve their goals.

The package of measures should include:

- introduction of audits of energy systems in industrial installations
- financial support for training and certification of energy auditors
- fiscal and financial incentives for investments in energy saving projects
- a framework for claiming emissions credits for investments in electricity saving (eg the 'White Certificates' in Italy)
- an information campaign based on the Motor Challenge Programme.

Benefit	Beneficiary	Annual Benefit (€ billion for EU-25)
Energy cost saving	Industry	10
Non-energy saving benefits	Industry	5-10
Reduced environmental costs	Society	6

Benefits of switching to energy efficient motor driven systems

Contents

1. Introduction

Motor driven systems account for approximately 65% of the electricity consumed by EU industry. New products and techniques hold great promise for large electricity savings. Implementing high efficiency motor driven systems, or improving existing ones, could save Europe over 200 billion kWh of electricity per year. This would significantly reduce the need for new power plants and hence free up capital and resources. It would also reduce the production of greenhouse gases and push down the total environmental cost of electricity generation. High efficiency motor systems can reduce maintenance costs and improve operations in industry.

Nevertheless, adoption of high efficiency motor driven systems has been limited by a number of factors, including their higher purchase cost and the lack of knowledge in the market place about their energy savings potential. Few people know that, in the majority of cases, investments in high efficiency motor systems have a short pay-back time. Effective regulation combined with information campaigns should help stimulate change and bring significant benefits to the European economy and environment. This would increase the competitiveness of European manufacturing industry and improve its position with respect to those regions that have already taken significant steps towards improving energy efficiency.

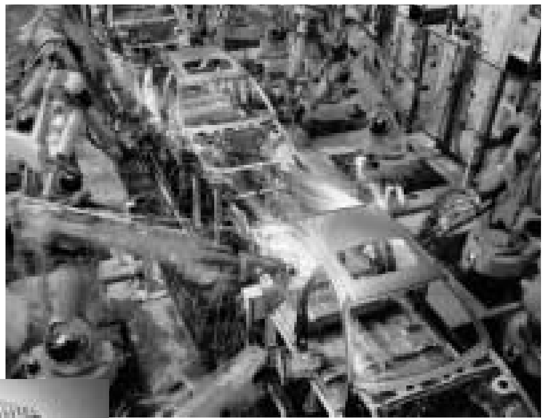
According to European studies [1 - 5], the best strategy is a mix of information campaigns, financial incentives and regulation. The Motor Challenge Programme has made a good start in raising the awareness of industry. To achieve the target benefits, however, more resources should be allocated.

A particularly promising concept is the EU emissions trading scheme, which could be broadened to enable companies to claim emissions credits for investments that reduce energy consumption.

Section 2 of this report provides a more detailed overview of the benefits of implementing energy efficient motor driven systems. Section 3 discusses the barriers, which are primarily technical and managerial, and Section 4 suggests possible actions to overcome them. Section 5 presents an overview of existing programmes and Section 6 proposes an action plan.

Annex I on page 16 provides a brief introduction to motor driven systems and their components and outlines case histories of energy savings achieved by improving efficiency of components and systems.

Annex II lists the references, identified by '[n]' in the text and Annex III contains notes referred to in the text, identified with a superscript.



Compressed air-driven robots in car manufacturing (Copyright Druckluft Effizient)

Motor driven systems are used extensively in Europe and account for 65% of industrial electricity consumption.

Motors and drives in a paper mill (Copyright ABB)

Baggage handling at Charles de Gaulle Airport (Copyright Siemens)

2. Benefits of Implementing Energy Efficient Motor Systems

The best kWh is the one that is saved. Indeed, saving energy is beneficial for many reasons. Less fuel needs to be burned and fewer power plants need to be built. This saves money as well as saving the environment. Motor driven systems consume about 65% of industrial electricity in the European Union. The SAVE studies supported by the European Commission [1-5] identified that, where modern high efficiency equipment was properly selected and installed, large energy savings were possible. Making energy savings a high priority is likely to yield significant financial benefits.

2.1 Electricity savings potential

Economic savings potential

Total electricity consumption in the EU-15[1] in 2000 was 2 574 billion kWh, of which 951 billion kWh was used in industry [6]. Of this, 614 billion kWh, or 65%, was consumed by motor driven systems. The SAVE studies [1-5] calculated the economical savings potential of those industrial motor driven systems[2] to be 181 billion kWh, or 29%[3]. This means a savings potential of more than 7% of the overall electricity consumption in the EU.

The above figure is the 'economic energy savings potential'. This is the savings potential of measures with a reasonable pay-back time, typically between 2 and 3 years. Its calculation is based on current electricity prices and can therefore vary with time. The 'technical energy savings potential' is the energy that would be saved by implementing all existing technical measures, without concern for economic efficiency. The technical savings potential is, of course, higher than the economic savings potential.

The motor and its application

Industrial facilities use very large numbers of motor driven systems, hereafter called motor systems. A motor system consists of the electric drive itself, sometimes a variable speed drive (VSD) and the driven load.

Compressed air, pumping or ventilation systems (see Annex I) represent about 60% of the motor loads. Other important uses include materials processing (mills, mixers, centrifugal machines, etc) and materials handling applications (conveyors, hoists, elevators, etc).

The efficiency of a motor system depends on several factors, including:

- motor efficiency
- motor speed control
- proper sizing
- power supply quality
- distribution losses
- mechanical transmission
- maintenance practices
- end-use mechanical efficiency (pump, fan, compressor, etc).

Figure 1 illustrates the synergistic effects of the combination of different energy efficient technologies to reduce the electricity consumption of a pumping system by more than half [4].

Table 1 specifies the energy savings potential in industry in the EU of using high efficiency motors (HEM), installing variable speed drives (VSD) and optimising the application part of the drive system.

2.2 Environmental benefits

Kyoto target

One of the major current environmental concerns is the 'greenhouse gas' emissions (CO_2, N_2O, etc) created by the use of fossil fuels. After signing the Kyoto protocol in 1997, the EU committed itself to reducing its overall

	Savings potential (billion kWh/year)					
	EU-15	EU-25	France	Germany	Italy	UK
High efficiency motors	24	27	4	6	4	3
Variable speed drives	45	50	8	10	7	6
Application part of the motor systems (pumps, fans, compressors)	112	125	19	26	17	15
Total electricity savings potential	181	202	31	42	28	24

Table 1 - Overview of energy savings potential for motor systems in the EU [5]

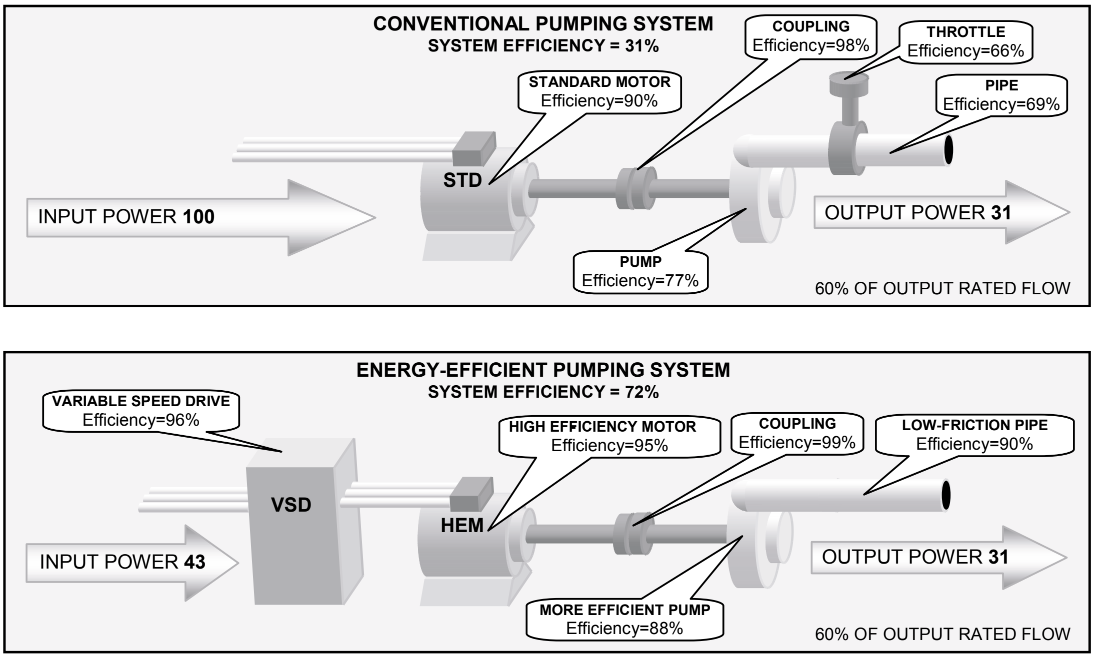


Figure 1 - a) Conventional pumping system (total efficiency = 31%)
b) Energy-efficient pumping system combining efficient technologies (total efficiency = 72%)

greenhouse gas emissions over the period 2008 to 2012 by 8% compared to 1990 levels, i.e. a reduction of 336 million tonne CO_2 equivalent (CO_2eq) [7]. This cannot be achieved without serious efforts in all areas of the economy, including the generation and use of electrical energy.

There are four ways of reducing CO_2eq emissions from electricity:

- increase the use of renewable energy sources
- increase the use of nuclear power
- through cogeneration and increased power plant efficiency (eg by using other fuels)
- energy saving.

Of these, energy saving currently offers the biggest potential at the lowest cost.

Power generation in the EU results in an average CO_2 emission of 0.435 kg CO_2/kWh [5] (EU-15, 1999). This means that the savings potential on industrial motor systems of 181 billion kWh (EU-15) corresponds to the saving of 79 million tonne CO_2, or 24% of the Kyoto target. This is the annual amount of CO_2 that would be saved by 360 million solar roofs, or that an average European forest of 355 500 km^2 transforms into oxygen[6], i.e. an area larger than Finland.

Table 2 shows the emission reduction potential as a proportion of the 'Kyoto gap', i.e. the difference between expected emissions and 2010 Kyoto target emissions:

- France: Emission reduction potential is small because of the high proportion of nuclear generation. However, improving efficiency of motor driven systems would release emission-free electricity for sale to other countries.
- Germany: Emission reduction is greater than the Kyoto gap, making an additional 10 million tonne CO_2 emissions available for trade.

	EU-15	EU-25	France	Germany	Italy	UK
Reduction potential for greenhouse gas emissions (Million tonne CO_2eq per year)	79	100	3	27	14	12
% of Kyoto gap	24%	-	6%	175%	26%	n/a

Table 2 - Overview of the CO_2 reduction potential related to efficient motor systems[7]

- Italy: Emission reduction represents 26% of the Kyoto gap.

- UK: Current policy measures are expected to meet the Kyoto targets. Emission reduction due to high efficiency motor driven systems would give the UK 12 million tonne of tradable credits.

Non-greenhouse gas emissions

The burning of fossil fuels for electricity generation produces various types of emissions. Apart from CO_2, the main offenders are SO_2 and NO_x[8], which contribute to the acidification of the environment. These pollutants have long range transborder effects and have therefore become a major concern for most European countries. The European Union participates in the UN sponsored Geneva Convention on Long Range Transborder Air Pollutants which is the international body attempting to reduce this type of pollution.

Additionally, emissions also contain heavy metals (nickel, zinc, chrome, copper, mercury etc) and dust. Although they can be substantially reduced by using the latest flue gas cleaning techniques, a small amount will always escape into the environment. Burning fossil fuels also produces fly ashes and solid ashes.

The 202 billion kWh that can be saved by optimising industrial motor systems means a reduction of 7% in the overall European electricity production, so it will lead to an equivalent reduction of all the emissions mentioned above.

Cost of burning fossil fuel

A European Commission research project[9] calculated the cost of the environmental impact of power generation in Europe. These "fuel cycle externalities" are the costs imposed on society and the environment that are not included in the market price, for example the effects of air pollution, influences on public health, occupational diseases and accidents.

There is a wide range in estimates for external costs reflecting, for example, political preferences, or the use of different technologies for power generation[10] (Table 3).

So the environmental cost of an average European kWh is calculated at around 3 eurocents. This needs to be added to the typical industrial market price of 5 eurocents/kWh. Current eco-taxation schemes in the EU member states do not internalise the full external costs of electricity generation[11].

Therefore, saving 202 billion kWh/year in electricity also means saving €6 billion of environmental costs for society.

Energy efficiency and energy sector investments

Improving the industrial motor systems in Europe (EU-25) could result in an annual saving of 202 billion kWh of energy consumption. This would eliminate the need for adding 45 GW of power generating capacity to the European electricity system[12]. This is equivalent to:

- 45 nuclear power units (1 000 MW)

- 130 fossil fuel power units (350 MW)

The 202 billion kWh is equivalent to about five times the electricity production of all wind power units in Europe (EU-25) in 2003 (5 x 40 billion kWh)[13].

According to [8], the EU needs to add 320 GW of new base load capacity in the next 30 years to cope with increasing electricity demand. This expansion will cost Europe between €200 and €300 billion and a similar additional amount of investment in transmission and distribution systems. High efficiency motor systems

Fuel	External cost range (€cent/kWh)	Mean value (€cent/kWh)	Generation in EU-15 (%)	Contribution to external cost (€cent/kWh)
Coal	5 - 8	7½	27	2.03
Oil	5 - 11	8	6	0.48
Gas	1 - 3	2	18	0.36
Nuclear	0.5	0.5	33	0.17
Hydro	0.3	0.3	14	0.04
Other	0.1	0.1	2	< 0.01
Total				3.07

Table 3 - External costs for the use of different technologies for power generation

would reduce this expansion need by more than 10% and would save Europe around €50 billion - or €5 billion capital cost a year (discount rate 10%).

2.3 Micro economical benefits

The pay-back periods for most investments in energy efficient motor systems are relatively short, ranging from 3 months to 3 years.

The non-energy benefits of higher efficiency systems are better process control, reduced disruption and improved product quality. Sometimes reliability is improved, but not always (a variable speed drive can be less reliable than a direct on-line system). Overall cost savings related to these benefits can be in the same order of magnitude as the energy cost saving itself [9-12]. So companies or organisations that invest in energy saving on motor systems also improve profit in an indirect way.

2.4 Macro economical benefits

Increased competitiveness

Using energy as efficiently as possible is a crucial requirement to maintain the competitiveness of the European economy. Since motor systems account for 65% of all industrial electricity use, they are the most important area of attention for cutting energy costs. The US has already created extensive programmes to stimulate energy saving with motor systems[14]. Falling behind the US would have long-term adverse consequences for the European economy.

Raised employment

Investments in high efficiency motor systems have the direct effect of creating jobs in three areas:

- energy service companies, engineering consultants, and contractors, many of which are SMEs.
- manufacturers of motors, variable speed drives, compressors, fans and pumps and other system components such as hoses, tubes or control systems.
- jobs in energy or maintenance departments; a shift from 'fire fighting' to condition monitoring and preventive maintenance that can increase the added-value of manufacturing.

Although most investments create employment, money can only be invested once. When faced with several choices, it is necessary to decide whether investing the same amount of money in another area would not create more jobs. In other words, when judging an investment, the overall net creation of employment and its influence on the whole economy should be considered.

Investing to reduce the energy use of motor systems pays back over a relatively short period, after which the energy cost savings are pure profit. Therefore, investing in high efficiency motor systems does not divert money from other essential areas. On the contrary, it even creates more money for new investments and, consequently, new jobs.

Reduced dependency of fossil fuels

Saving 202 billion kWh a year (EU-25) also improves Europe's security of supply and reduces dependency on fossil fuel imports. It represents 42.5 million tonne oil equivalent annually, reducing imports of primary fuel by 6%[15]. Therefore, saving energy on motors would allow more time to develop alternatives for fossil fuels. With just this argument in mind, it would even be defensible to look beyond the current economic savings potential of motor systems (calculated with the current kWh price, see 2.2), and to encourage technology that can make them as energy efficient as possible. In other words, in the long-run, a large portion of today's technical savings potential could become tomorrow's economic savings potential.

3. Market Barriers

If the savings potential of energy efficient motor systems is as high as described in Section 2, why does it receive so little attention? What are the restraints preventing implementation of energy efficient drive systems? If those restraints are removed, which mechanisms can still block the actual implementation of more efficient systems?

Studies show that a whole spectrum of causes exist [1-5]. Some of them are specific to certain industrial sectors or certain categories of motor systems (eg pumps, compressors, fans). Nevertheless, some general observations stand out. The following nine types of market barriers, grouped into categories according to importance, describe the largest part of the problem:

Major barriers

1. Pay-back time is too long due to low electricity prices
2. Reluctance to change a working process
3. Split budgets

Medium barriers

4. Not all parties in the supply chain are motivated
5. Lack of correct definitions of motor system efficiency
6. Oversizing due to lack of knowledge of mechanical characteristics of load
7. Lack of management time

Moderate barriers

8. Shortage of capital
9. Other functional specifications conflict with energy efficiency.

3.1 Major barriers

Pay-back time is too long due to low electricity prices

In general, energy efficient motor systems have reasonable to very good pay-back times, but some companies still consider these to be too long to be of interest.

This is often because the economics are based on simple pay-back times instead of the more appropriate internal rate of return. A pay-back time of two years is about equivalent to a rate of return of 50% [13].

It was established in section 2.2 that not all of the costs of providing electricity to society are included in the market price. As a result, when a kWh is saved, not all of the benefit goes to the company that made the effort. A significant part of the benefit is to society and is never taken into account in a purely financial analysis. To make matters worse, liberalisation enables large electricity users to use their market power to negotiate a lower price, thereby further reducing the incentive for saving energy.

Reluctance to change a working process

Often, the idea of switching to more energy efficient systems is only considered when a component, such as the motor, fails. In such a case, a decision has to be taken quickly and energy considerations are left aside. Repairing the motor often seems to be the fastest and thus cheapest option. This often means a missed opportunity for switching to a more energy efficient model. In general, a repaired motor has a lower efficiency than a new motor, although a high quality repair of an old motor can actually improve efficiency by, for example, the use of better insulation materials. The replace-repair decision needs to be part of a motor management policy and energy considerations should be taken into account.

If the decision is made to replace the motor, there is usually no time to reassess the system. More often than not, exactly the same type of motor will be purchased.

Another problem is that many sites have stocks of older, salvaged motors and use these 'free' motors as replacements.

For compressed air, pumping and ventilation systems with downstream piping, a further complication is that efficiency upgrades may only be possible during scheduled maintenance periods. However, minor maintenance procedures, such as the repair of leaks, can be performed on an operating process.

Split budgets

There can be a situation in which one budget is used to spend money so that another budget can show savings. For instance, investing in new parts of a compressed air or pump system can be the responsibility of the maintenance department and earmarked for its budget, while the savings due to energy efficiency accrue to a budget of general costs.

It also happens that the energy costs are not apportioned to individual production areas; another case where little incentive is generated to reduce energy use.

3.2 Medium barriers

Not all parties in the supply chain are motivated

Many intermediate stages exist between the manufacturer of a motor system and the department that will actually be using it and paying the bill for the energy use. In other words, the interests of those in the supply chain focus on first cost while users' interests should focus on lifetime costs. If any element of the supply chain is not aware of the importance of energy efficiency, the spread of energy efficient motor systems will stall.

Components and sub-systems, like motors, fans and pumps, for instance, are often manufactured by OEMs, driven by their clients to supply at the lowest cost. Moreover, systems are often sold via distributors who are not always aware of the importance of energy efficiency.

A complete pumping, ventilation or compressed air system is often designed by engineers and installed by engineering contractors, introducing two further parties to be convinced but without a stake in energy conservation.

Also on the procurement side, intermediate parties can block the move. Some larger companies have purchasing policies that impose the same specifications for all their purchases. These specifications often become outdated, so that less efficient models continue to be purchased without question. Another example is the use of fans for indoor climate systems. These are often restricted by contracts between the building owner and the supplier stipulating that the fans meet functional requirements, ignoring the energy issue.

Lack of correct definitions of motor system efficiency

The efficiency of motor systems is often difficult to define and calculate. The EU/CEMEP system divides the motors into three clearly defined classes. This should help overcome the historical barrier of the lack of a precise definition of what constitutes a high efficiency motor. However, for complete motor systems such as fans or pumps, the lack of a clear definition persists. The efficiency of a complete motor system is much more difficult to assess than the efficiency of a motor alone. Diverse efficiency test methods result in different values causing some scepticism among purchasers who then tend to ignore manufacturers' efficiency data.

Oversizing due to unknown mechanical load characteristics

Installing a high efficiency system is pointless if it is oversized for the job, yet it often happens. The system's mechanical load characteristics may be difficult to determine or may be overestimated or the size may be determined by start-up, rather than running load. Sometimes regulations prescribe a large safety margin. In other cases, the specifications for new systems are determined allowing for future plant expansion.

Lack of management time

In general, the concept of investing in energy efficient motor systems is raised by an engineer. However, engineers are typically weak in 'selling' the project. They refrain from translating the arguments into terms familiar to decision makers and, for this reason, sound investment opportunities can be rejected by the financial managers.

Sometimes there is a senior management commitment, but the distribution of the commitment between the divisions and departments of the company goes wrong. The engagement lacks a clear action plan. In that case, conflicting pressures mean that well-intended commitments are soon forgotten.

3.3 Moderate barriers

Shortage of capital

Shortage of capital makes it difficult for companies to invest in more efficient systems, despite potentially profitable opportunities. In such cases, the limited capital available is usually reserved for investments that are clearly compatible with strategic business objectives.

Energy services companies (ESCOs) can help to overcome this barrier, but need support.

Other specifications conflict with energy efficiency

Even when energy efficiency is taken into consideration, it is often given lower priority than other issues. Many companies assign the responsibility of motor systems to the maintenance department. Logically, they view the availability of production assets, their maintenance effort and costs as priorities. Sometimes this is in conflict with energy efficiency. A variable speed drive, for example, saves energy but is also sensitive to voltage dips and introduces harmonics.

4. Solutions

Overcoming market barriers

How can the barriers described in Section 3 be overcome so that the European market for motor systems can be transformed? The conventional wisdom is that a good mix of actions, spread intelligently over time, is the best way. Co-ordinating all activities under a single central programme will enhance the clarity of the benefits for the target audience and help to achieve the goals.

One proven tactic for changing a market is the three-tiered approach of the carrot, the stick, and the tambourine. The carrot represents the incentives, the stick regulation, and the tambourine stands for education. All three pillars are equally important.

The most important actions to overcome the barriers and achieve success can be summarised as follows:

1. *Regulation* - for example creating efficiency classes, licensing of motor systems as a part of the Integrated Pollution Prevention and Control (IPPC) operating licence of industrial installations, and mandatory audits.

2. *Information and education* - providing publications and seminars, tackling issues from the point of view of the target audience.

3. *Shop floor assistance* - decision-support tools (electronic databases, energy savings calculators, education of personnel on the job and, above all, energy audits).

4. *Financial support* - kick-start promotional rebates, support of distributors, enhanced capital allowances, special leasing contracts and the trading of emissions credits. In each case, incentives should be of adequate value in order to be successful.

5. *Working with suppliers* - the ideal partners for distributing information, but a perceived loss of independence should be avoided.

6. *Environmental standards* - accreditations like ISO 14001 as a framework to promote efficiency.

7. *Supporting R&D of manufacturers* - supporting R&D directly or indirectly results in designing more energy efficient products.

8. *Procurement & life cycle costing* - a proven technique to increase business and environmental performance at the same time.

9. *Integrated approach* - none of the above solutions will work in isolation but, combined, provide a powerful tool for change.

4.1 Regulation

Section 3 (Market Barriers) describes the importance of establishing an agreement over what exactly constitutes a high efficiency motor system. A first step in achieving agreement is to define efficiency levels. When these levels have been established, motors can then be officially classified and labelled. This phase has already been accomplished for the motors themselves. The EU/CEMEP system divides motors into three well-defined classes: EFF3, EFF2 and EFF1 (EFF1 being the highest efficiency). It is important to note that energy efficiency standards, whether they are voluntary or regulated, should not be seen as fixed, but rather as something constantly being re-evaluated to determine the right time to increase it to a higher level. Experience has shown that EFF3 motors are now a negligible fraction of the market, but the same is true for the EFF1 motors. In other words, the voluntary scheme has moved the market focus onto EFF2 motors. To move the market to EFF1 motors, and allow the huge cost-effective energy savings to be tapped, there may be a need to impose mandatory minimum efficiency standards.

For the complete motor system, such labelling is often difficult. This is because the efficiency levels of those systems not only depend on the machines purchased, but just as much on the method of installation and operation. A possible way to ensure energy efficiency could be to:

- recommend best practice for motor system efficiency in the IPPC operating licence for industrial sites[16]
- implement a mandatory auditing scheme, currently foreseen in the draft directive on energy services[17].

Classification and labelling are still a good idea for standardised motor systems that are usually sold as an integrated unit.

For fan systems, there are at present several different efficiency test standards in the EU. A single, widely accepted standard would, of course, be better. Once there is a consensus regarding such a standard, manufacturers and users can then meet to develop a labelling scheme.

For smaller water circulation pumps a definition of general efficiency levels is still lacking. One problem is that the tolerances of published pump data are currently too large to allow for a higher number of efficiency levels. Reducing these tolerances would be a good start.

4.2 Information and education

Publications and seminars are the main tools for distributing information. Various types of publications already exist on the subject but many of them merely arouse interest and are not detailed enough to be of practical value. In contrast, there are also very specialised, learned papers available that require close reading and are more suited to academia. It is the gap between these two extremes that needs to be filled.

An important point is that the publications should be technically sound and always written with the target audience in mind. There are many different groups of people involved in the selection of a motor driven system, from maintenance staff to accountants, and appropriate information has to be available for all of them.

Another successful way of spreading information is through seminars. Here the remarks regarding publications are equally valid. They should avoid being too general on the one hand and too academic on the other. The best seminars are those with a very practical agenda, leaving plenty of time for discussion. An engineer who tells an energy saving story from real-life experience can bring the whole event to the level of the audience. The most effective speakers are those who are not only technically competent, but also good presenters. In order to be able to present interesting case stories in publications and seminars, it is a good idea to set up demonstration and pilot projects that deal with specific problems. It must be remembered, however, that every presentation needs to be impartial to be credible. The best method for evaluating the effectiveness of seminars is through the use of formal evaluation questionnaires, completed by the seminar attendees.

Involving equipment suppliers is also a good idea, both as speakers and exhibitors. It can be a good way to reinforce their necessary commitment (see Section 3: Market Barriers).

4.3 Shop floor assistance

In general, shop floor assistance by an independent specialised advisor is the best guarantee that optimum energy saving measures will be identified; the whole motor system needs to be assessed, not just the motor itself. Stimulating and supporting audits is probably one of the measures with the highest return on investment a government can take. Along with actual advice, advisors can also educate personnel on the job and can even help them present appropriate investment proposals to management.

Special 'energy savings calculators' are a good way to focus initial attention on energy savings potential before an advisor is called in for an audit. While calculators do not use methods that consider every variable necessary for a completely accurate result, their approximations can indicate where there are good energy saving opportunities. This can be a very successful method of raising initial awareness.

Electronic databases, for example EuroDEEM[18], that compare different motor options, are also a good support tool, though their use sometimes suffers from a general reluctance to learn how to use new software. Training sessions, such as those given in seminars, can be a good way of overcoming this barrier.

4.4 Finance mechanisms

Rebates are a very simple way to encourage the sales of energy efficient motor systems. The rebate programmes of US utility companies in the 80s, however, show that it is not always the most cost-efficient way of reaching the goal. To be effective, a rebate scheme must offer an adequate value and this makes these programmes very expensive. As the sale of energy efficient systems increase, the 'free rider' effect - people who would have bought those systems anyway - makes rebate schemes progressively less effective. They are a good way to kick-start promotional and legislative measures, but are best phased out as the market develops.

The support of distributors is of vital importance. They need to allocate enough space to stock high efficiency systems. Distributors must have a financial incentive to participate and, even more importantly, they must believe in the effectiveness of the overall programme.

One way of giving financial support is to make allowances on company taxes when investments are made in energy efficient motor systems. The UK Enhanced Capital Allowances Scheme (ECA scheme, see Section 5) is a good example of such a programme.

Another type of financial support is leasing. This is usually offered by the manufacturer and, if necessary, supported in some way by government. Its principal attraction to customers is that they can achieve savings without having to spend capital. Contracting is usually offered for larger motor systems, such as compressed air systems. Some special contracts even specify that the customer pays the contracting company only from savings in energy costs. This is an excellent way of completely overcoming the barrier of capital shortage.

Financial assistance can be provided through energy service companies (ESCOs), third party financing or performance contracting.

A particularly promising concept is the EU emissions trading scheme, which could be broadened to allow companies to claim emissions credits for investments in energy reducing equipment. This follows the principle that the saved kWh is the most environmentally friendly kWh. If a company saves a kWh, this results in a kWh less to be produced by the power station, and consequently a reduction of the greenhouse gas emissions from the power station. At present, the power station can receive emissions credits for this reduction. But, to be fair, and to stimulate energy savings investments, the company that made the investment in energy savings measures should get at least a share of those credits.

Also, revenue obtained from carbon taxes could be recycled to finance energy-efficiency investments. This would make those taxes neutral for European industry, while at the same time helping to improve its competitiveness.

4.5 Working with suppliers

Since equipment suppliers visit customers on a regular basis, they are the ideal partners for distributing information. These suppliers are not necessarily manufacturers. It is critical that the actual OEM equipment distributors are reached. Working with suppliers requires a delicate balance between the free promotional effort and the perceived loss of independence. It also risks the loss of credibility since companies aim to profit from selling products or services.

4.6 Supporting the R&D of manufacturers

The maturity of standard motors and the huge cost involved in making significant advances means that there are rarely opportunities for making cost-effective efficiency improvements. The same is true, to a lesser degree, for complete motor systems such as pumps, compressors and fans. Recently, however, a French company announced that their production process for manufacturing copper rotors is ready for the market. The process has, up to now, always been impossible to industrialise because of the high melting point of copper (around 1 083°C). Because of copper's high conductivity, this new process increases efficiency of the motor by 3%.

A good way for stimulating R&D, and for the development of energy efficient products, are Product Procurement Groups. These are groups of users that offer manufacturers a guaranteed market if they develop a new product to meet a particular specification.

4.7 Setting environmental standards

ISO 14001 and EMAS [14] accredited companies can be an interesting target for motor system efficiency improvement. Such efficiency improvements can be reported as an improvement in the company's environmental performance.

The IPPC directive [15] requires industrial installations falling under it to apply best available technology for energy efficiency, among other things. This includes high efficiency in motor driven systems.

4.8 Procurement and life cycle costing

Life Cycle Costing (LCC) is a forceful tool to improve business performance and, at the same time, protect the environment by reducing energy consumption. LCC guidelines have been developed in the SAVE programme[19]. They are primarily intended for application in procurement work in the engineering industry and may be included as part of a procurement manual or a quality system in industry. The target group includes industry management, purchasers, consultants, contractors and manufacturers.

4.9 Need for an integrated approach

A successful programme needs to incorporate several of the above actions, in a coordinated approach to change the market. Regulation is needed on minimum efficiency performance standards for different parts of motor systems. Actually, so far, only motors have been addressed. To realise the savings potential in motor systems energy audits are essential, but they need to be supported by a regulatory framework of periodic inspections. Such inspections can cover all energy systems at a plant. In order to maintain quality, inspectors need to be trained and, where necessary, certified. Information and promotion need to work in parallel, in order to train users to comply with the requirements of any new regulations. Test cases need to be developed in the market, preferably with industry leaders, to demonstrate the benefits of high efficiency motor systems. Often, lack of capital is a barrier, and needs to be addressed by financial schemes, such as performance contracting or tax incentives.

5. Ongoing Programmes

A number of programmes for promoting enhanced motor system efficiency have been initiated in the European Union and the United States. They each concentrate on certain types of activities (see Section 4).

A short description of each of these programmes is given below, followed by the most important lessons that could be derived from them.

Regulation

1. The European Motor Challenge Programme - a voluntary programme instituted by the European Commission to improve the efficiency of motor driven systems
2. France - 1977 Energy saving decree - requires mandatory energy inspection in industry
3. Italy - 2001 Energy efficiency decree - linked to liberalisation, it requires distribution utilities to implement an energy saving programme with quantified, progressive annual targets
4. EU motor efficiency labels - devised by the European Committee of Manufacturers of Electrical Machines and Power Electronics, and the European Commission
5. US EPAct - the Energy Policy Act describes the minimum standards for energy efficient motors
6. US NEMA Premium - the National Electrical Manufacturers Association labels high efficiency motors.

Information, education and shop floor assistance

7. EuroDEEM - the European database of efficient electric motors
8. EEBPp - the UK government's Energy Efficiency Best Practice Programme
9. Efficient Compressed Air Systems 'Druckluft Effizient' - a German programme to inform users about savings potentials in compressed air systems
10. European Guide to Pump Efficiency - a first example in Europe for classification and labelling of pumps.

Financial incentives

11. ECA - Enhanced Capital Allowances by the UK government.

Integrated programmes

12. Sparemotor - The Danish government gave subsidies for high efficiency motors as part of a larger campaign
13. Polish Efficient Motor Programme (PEMP) - supported by the United Nations and Global Environmental Facility, this programme includes dissemination, demonstration, financial incentives and definition of regulation.

As can be seen from the list above, there are only a few programmes that address motor systems. Most programmes focus on the motor, as motors alone are much easier to handle and to understand but, at the same time, many saving opportunities are missed by failing to take the motor system approach.

5.1 Description of the ongoing programmes

5.1.1 The European Motor Challenge Programme

The European Motor Challenge Programme (MCP) is a voluntary programme supported by the European Commission to improve the efficiency of motor driven systems. The 'Partner Companies' in the Motor Challenge Programme do not have legal obligations, but a strong commitment is required. The core of the programme is the Action Plan, in which they commit to undertake certain measures. The companies themselves define the scope of this Plan. In order to succeed, they receive advice and technical assistance from the Commission and a National Contact Centre. In addition to this operational advice, the Partners receive public recognition through the programme's promotional campaign.

The 'MCP Endorsers' are companies or organisations that wish to support the Motor Challenge Programme with their knowledge and help to promote MCP to industry. They have to write and execute an MCP Promotion Plan defining specific actions to disseminate information and support MCP Partners in putting the recommendations into practice. In return, the Endorsers receive public acknowledgement similar to that of the MCP Partners.

The number of companies joining the MCP is gradually increasing. It is still too early to provide valid statistics on the total energy savings, but it is already clear that a voluntary programme will never win over the large majority of motor system users.

5.1.2 France - 1977 energy saving decree

Regulatory measures [4] are used by governments to impose certain energy saving technologies. This is done routinely in building regulations, for example. In France, the July 5, 1977 decree instituted a broad system of mandatory energy inspections in industry. Finland also has a mandatory auditing scheme.

5.1.3 Italy - 2001 energy efficiency decree

In 2001 an energy efficiency decree was approved in Italy. The decree is connected with the liberalisation of the electricity market and requires electricity utilities to implement energy saving programmes in order to increase energy efficiency in end-use and meet quantitative targets. The decree requires electricity distributors to identify, finance and implement a specific energy saving programme. The suggested measures, listed within an attachment of the decree, include the adoption of high efficiency electric motors and variable speed drives in all sectors. The quantitative objectives to be reached by electricity distributors are fixed and progressive each year.

At the moment the decree is not in effect because a revision is in progress.

5.1.4 CEMEP and the efficiency labels

CEMEP (the European Committee of Manufacturers of Electrical Machines and Power Electronics) and the European Commission have devised motor efficiency classification labels - EFF1, EFF2 and EFF3 - to make it much easier for purchasers to identify energy efficient motors on the market. The programme was implemented by a voluntary agreement between the Commission and the motor manufacturers to reduce sales of EFF3 motors by half by 2003, a target which has been reached.

5.1.5 US EPAct (the Energy Policy Act)

EPAct was passed in 1992 to reduce US dependence on imported petroleum, to enhance the nation's energy security and improve environmental quality. One section of EPAct relates to energy efficiency of motor systems.

5.1.6 NEMA Premium (National Electrical Manufacturers Association)

NEMA Premium is a US energy efficiency motors programme. NEMA invites member motor manufacturers to participate in a voluntary partnership under which an efficiency audit of their products is made. If the products comply with the NEMA Premium motor efficiency guidelines, they may be NEMA Premium™ labelled, helping purchasers identify high efficiency motors.

5.1.7 EuroDEEM - the European motor system database

To include all the necessary factors when calculating efficiency, the European Commission developed the EuroDEEM software (the European Database of Efficient Electric Motors). For instance, load conditions, temperature and power quality can result in significant efficiency variations when in operation. With EuroDEEM, companies have an assessment tool to consider and optimise motor efficiency.

5.1.8 United Kingdom - EEBPp (Energy Efficiency Best Practice Programme)

The EEBPp is the UK Government's principal programme for information, advice and research on energy efficiency. It is directed at organisations in both the public and private sectors. Since its establishment in 1989, it has helped many organisations to save up to 20% on their energy bills. It has already led to energy savings in the UK of around £650M a year. It also maintains the biggest library of independent information on energy efficiency in the UK.

The EEBPp promotes best practice through free publications and events, and encourages action at every stage (planning, design, implementation and management). It also supports R&D on energy efficient motor systems.

5.1.9 Germany - Druckluft Effizient

Since 2001 the German campaign Druckluft Effizient (Efficient Compressed Air) has been aiming to improve the efficiency of compressed air systems in Germany. The campaign follows the system approach, looking at all components such as generation, treatment, distribution and end use. The main elements of the campaign are a large website with practical information, case studies and tools to improve compressed air systems, a free compressed air audit campaign, an efficient compressed air award, a contracting guide, a compressed air seminar and compressed air benchmarking. The campaign is supported by a partnership between the private sector and government.

5.1.10 European guide to pump efficiency

This application guide, developed by a project team, with support from the European Commission, allows users to select an efficient pump. It has been published jointly by the European Commission and EUROPUMP, under the Motor Challenge Programme[20].

5.1.11 United Kingdom - ECA (Enhanced Capital Allowances)

The goal of ECA is to reduce carbon dioxide emissions. This programme offers companies who invest in low carbon technologies and energy-saving systems the option of writing off their entire capital expenditure in the same year as their investment. Companies can source the relevant approved products from a list, updated monthly.

5.1.12 Denmark - Sparemotor

Between 1996 and 1998 this campaign educated Danish trade and industry on the advantages of replacing old electric motors with high efficiency motors. The campaign approached 4 000 companies through newspaper advertisements, newsletters and folders. The campaign website can help interested companies compare high efficiency and standard motors and also includes a list of energy efficient motors. In addition to this information campaign, a subsidy of €60/kW was given for a certain period of time.

The campaign was a success with almost 100 000 new energy efficient motors sold between the start of the campaign in 1996 and 1999, one year after it ended.

5.1.13 Polish Energy Efficient Motors Programme (PEMP) from United Nations Development Programme - Global Environment Facility

The Polish Energy Efficient Motors Programme (PEMP) aims to overcome the barriers to increased market penetration of energy efficient motors and related efficiency improvements in electric motor systems[21]. The project has four main activities supported under the GEF. The first focuses on building capacity and raises awareness by providing information and services related to energy efficient electric motor systems. The second involves demonstration projects to establish and showcase the technical and economic benefits of energy efficient motor systems and to increase awareness. The third has the objective of stimulating market transformation and competition through a financial incentive mechanism, supported by coordinated and targeted awareness raising activities. The fourth, a policy component, comprises both institutional and information instruments, and has been identified as a separate component because it addresses a different target group and requires a different approach at a national government level.

5.2 Critical success factors

From the programmes described above, several conclusions can be drawn. These are a few of the critical success factors for every programme that aims to promote high efficiency motor systems in Europe:

1. A legal framework
2. Adequate support
3. High quality information, in relevant terms
4. Streamlined with other programmes
5. Measuring results and giving feedback
6. Involvement and co-ordination between different interested parties
7. Differentiating for each separate market.

5.2.1 A legal framework

Most countries have no legal framework for favouring high efficiency motor systems. The success achieved in those countries that do (Denmark, US) shows the potential benefit of such a step. The European Motor Challenge Programme certainly lacks the support of a legal framework and financial resources.

5.2.2 Adequate support

Ongoing programmes show that the more resources that are invested, the higher the return. This does not mean that all the support needs to be in the form of financial incentives. Also other kinds of campaigns need enough financial support to maintain a minimum quality. Programmes in the UK and Denmark show that investing in large, high-quality programmes pays off.

5.2.3 High quality information, in relevant terms

All materials and communications must be of high quality. Low quality information reduces the credibility of the message. Messages need to be formulated in terms that are relevant and appropriate to the target audience. It should be understood that energy efficiency is rarely a key driver: other issues, such as maintenance and energy costs, are very important for many sites. Information is also more acceptable when it comes from a neutral source such as a public body or a research, non-profit making or teaching organisation.

5.2.4 Streamlined with other programmes

If the number of programmes and the amount of material become too large, the audience can become confused by multiple messages from multiple sources. Attention should be paid to streamlining all related activities, especially in those countries that have more resources for promoting energy saving, so that the message is clearly delivered.

5.2.5 Measuring results and giving feedback

For every programme built-in methods of evaluation and measurement are essential. This is indeed the only way to monitor impact and to fine-tune the programmes.

5.2.6 Information and co-ordination between different interested parties

All stakeholders in the market, including equipment suppliers, distributors, purchasing divisions of large companies and other key players, need to act as partners.

5.2.7 Differentiating for each separate market

The structure of the motor systems market shows a significant variation within Europe, even within Western Europe. As a result, no single action is likely to bring about a significant change throughout the entire European motor market. The best strategy seems to be the development of a combination of well-designed activities, in the right sequence, which match the requirements of the various national markets.

5.3 A textbook case

An example of a programme that successfully deals with all of the critical factors given above is the British Columbia Hydro Project in Canada. It clearly demonstrates how a market can be transformed by a properly structured campaign. (See Figure 2).

- Large incentives (covering more than the difference in cost between efficient and standard motors) had a major impact at the start of the project. This was slowly reduced as the programme matured.
- Support was generated by customer visits and the selection of tools. The high proportion of motor energy used in the mineral and paper industries meant that these companies were very ready to consider the HEM proposition.
- Distributors received 20% of the incentive value.

By 1993 over 60% of motors sold to OEMs were HEMs. This figure is due to the fact that many OEMs were selling equipment to the local market.

In 1995 minimum efficiency standards were introduced and rebates were halted.

Why did it work?

- The project provided for a major rebate programme, with attractive incentives for both purchasers and distributors.
- It provided for a substantial education programme, including both customer visits and a good database of available motors.
- The Canadian province of British Columbia has large industries keen to support energy efficiency improvement initiatives.
- Many OEMs were selling to the local market.
- The initiation of the minimum efficiency standards regulation made people take more notice.

The unanswered question is what would have happened without the minimum efficiency standards?

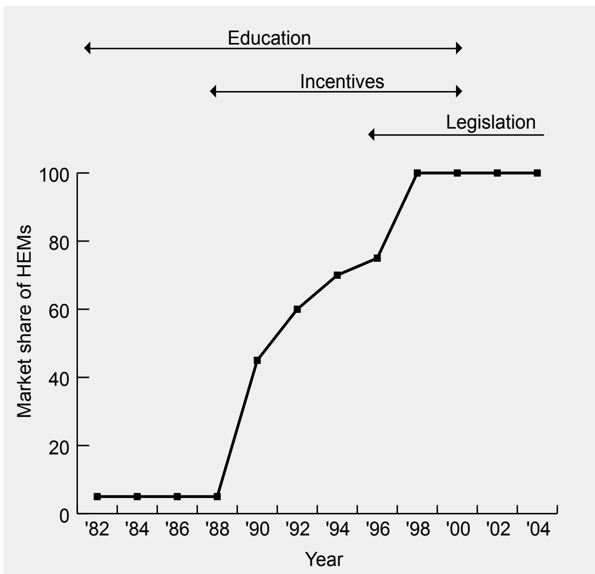


Figure 2 - Example of successful market transformation (British Columbia Hydro Project)

6. Conclusion

Realising the savings potential of 202 billion kWh for the EU would benefit European industry, society as a whole, save up to €10 billion a year and contribute to EU energy policy objectives. However, without action by government this potential will not be realised, despite the strong economic drivers. The market will not deliver energy efficiency because of technical and managerial barriers explained in Section 3.

The actions described in Section 4 are well known and have been demonstrated in the market place. The optimal mix of actions includes regulation, financial incentives and information campaigns. Because of the excellent financial pay-back, both government and industry can justify a large-scale investment to realise this savings potential.

1. Along with the direct financial benefit of saving energy, a saving of €6 billion per year can be made for European society in reduced environmental costs (EU-25, calculated using the EU-15 fuel mix). Allowing industry to trade the greenhouse emissions for improved energy efficiency could be a good measure; this measure alone would internalise about a third of environmental costs.

2. High efficiency motor systems also bring secondary cost benefits to industry through reduced maintenance costs and improved operations. These savings can be estimated at €5 -10 billion per year.

If we take into account an annual avoided cost of only €16 billion (electricity saving and avoided environmental pollution), and require a 3 year pay-back time, this results in a potential investment of €48 billion, to be spread over 10-20 years.

A role for government

A four-year package of measures is suggested, investing €400 million in the motor systems market. The programme should run at national level in the EU member states. The Motor Challenge Programme should continue to be a forum for developing common tools and fast learning. Measures should include:

- the introduction of audits of energy systems in industrial installations

- development of energy services to help industry implement cost-effective measures in motor systems

- financial support for training and certification of energy auditors

- fiscal and financial incentives for investments in energy saving projects

- a framework for claiming emissions credits for investments in electricity saving (eg the 'White certificates in Italy, [16])

- an information campaign based on the Motor Challenge Programme.

While €400 million may seem a large amount, this needs to be evaluated against the contribution the programme could make to specific energy policy objectives, such as reducing greenhouse gas emissions and improving the security of supply. Revenue from carbon taxes may provide some funding, while another part may be implemented through measures designed to be neutral on the public budget. Some cash portion, however, needs to be provided to support the information, education, training, audits and inspections.

A role for industry

Industry's role is to embrace initiatives such as the Motor Challenge Programme and invest in staff training and high efficiency systems. This could be done within the framework and the support created by government.

The investment requirement of €48 billion is actually very close to the €50 billion investment in power plants that efficient motor systems would make unnecessary. It is therefore suggested that, instead of building additional power plant capacity, a better alternative is investment in energy efficient manufacturing systems. In this way environmental performance is increased and Europe's energy dependency reduced. Existing power plant capacity would, of course, need to be maintained with old power generation plant being replaced at the end of its life by new plant.

Annex I: Motor Systems

Definition of a motor system

In this report 'an industrial motor system' is any system driven by an electrical motor consisting of:

- the electrical motor drive
- sometimes, a variable speed drive (VSD)
- the system that is driven by the motor, eg:
  - compressed air system (comprising the compressor itself and the whole distribution network)
  - a pump system (comprising the pump itself and the piping)
  - a fan system (comprising the fan itself and the whole distribution ducting)
  - mixers, conveyor belts, packaging machines...
  - end use devices (eg compressed air tools, pneumatic cylinders).

The electrical motor drive

All electric motors consist of a rotating part, the rotor, and a static part, the stator. The rotor turns through the interaction of the magnetic fields of the rotor and the stator.

There are several types of electrical motor drive. By far the most widely-used in industry is the induction motor, also called the asynchronous motor. They exist in all ranges of power, except very low or very high. In an induction motor, the stator contains copper windings, connected to a power supply. Because of the voltage across the winding, a radial rotating magnetic field is formed. This induces a current into conductive loops in the rotor and creates forces on these conductors that make the rotor turn. The turning movement can then be used to drive a system. This type of motor is called 'asynchronous' because the mechanical rotation is a little slower than the rotation of the magnetic field.

High Efficiency Motors (HEMs)

The efficiency of electrical motors can be improved mainly by:

1. Reducing the losses in the windings. This is done by increasing the cross-sectional area of the conductor or by improving the winding technique to reduce the length
2. Using better magnetic steel
3. Improving the aerodynamics of the motor
4. Improving manufacturing tolerances.

Motors with improved efficiency are called 'High Efficiency Motors' or HEMs.

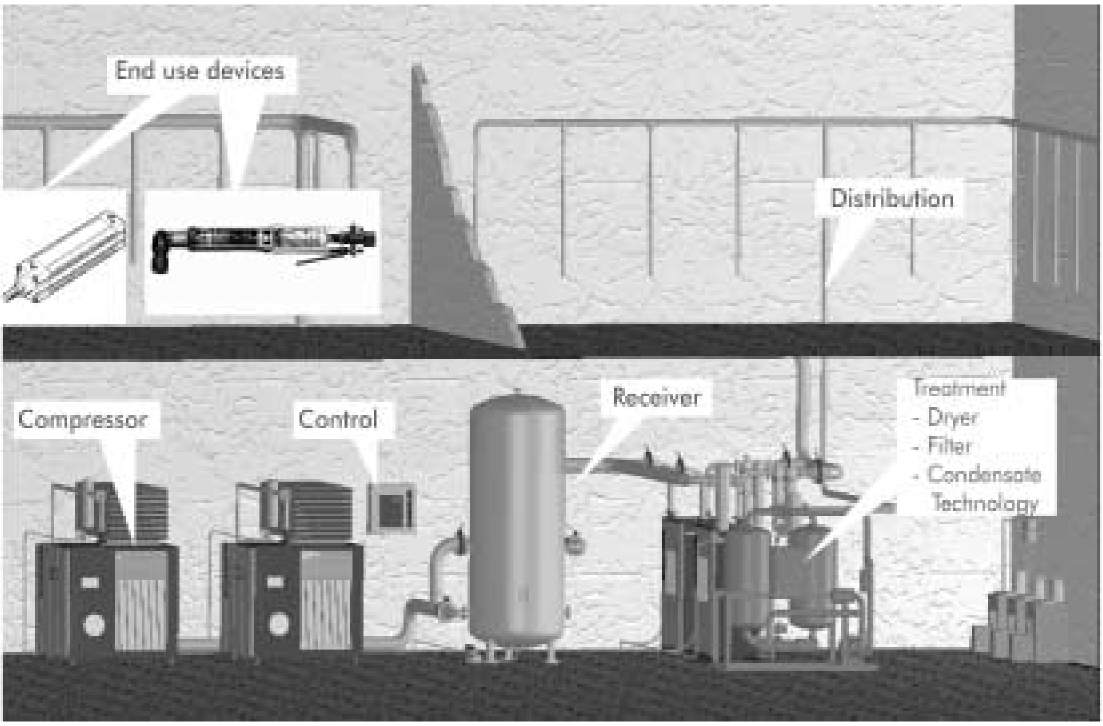


Figure 3 - A compressed air system
(Copyright Druckluft Effizient)

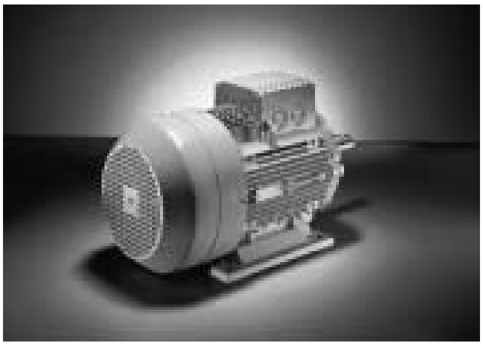


Figure 4 - A low-voltage induction motor (Copyright Siemens)

Case history

At Delta Extrusion (UK brass mill), five motors were replaced with higher efficiency motors to give a reasonable cross-section of the range of cast iron motor ratings. Three of the motors were running continuously. The remaining two ran on a 5-day/3 shift operational pattern.

Measurements showed that the 5 motors saved 12 MWh/year. The overall payback for the investment premium in 5 high efficiency motors was 1.6 years. The range of payback on individual motors was between 9 months and 3.4 years[22].

Variable Speed Drives (VSDs)

A VSD varies the feeding frequency and voltage of the supply to the motor, thus controlling its speed. It is built using power electronics components.

If correctly applied, this kind of speed adjustment can lead to better process control, less wear in the mechanical equipment, less acoustic noise and significant energy savings. Special attention should be paid to avoid the introduction of disturbances in the power quality of the supply.

They should not be added in systems operating mostly at full load as the electronics add losses in the range of 3%. If a system often operates at part load, these extra losses are over-compensated by savings and a VSD becomes profitable.

Case history

Hanson Brick reduced its electricity use per brick produced by 8.7% through the use of variable speed drives. Overall pay-back of the investment was 1.4 years [17].

Compressed air systems

Compressed air is a frequently used energy source in industry. An electrical motor drives a compressor. The compressed air is distributed, through a network of pipes, all over the production site to the end use devices (car industry robots, high pressure spraying pistols, etc).

System performance depends on the performance of each element, yet overall system design and operation have an even greater influence on performance. Together with the use of high efficiency motors and variable speed drives, the following technical measures could improve the overall performance of a compressed air system:

- an optimal choice of the type of compressor for the specific end use applications
- the improvement of compressor technology (eg multi-stage compressors)
- the use of sophisticated control systems
- the recuperation of heat for use in other functions
- improving air treatment (eg drying, filtering)
- a better overall system design, including the introduction of multi-pressure systems
- improving the air flow in pipework to reduce the pressure losses caused by friction
- reducing air leaks
- optimising specific end use devices.

Porsche received the 'Compressed Air Efficiency' award in 2003 for the measures taken to improve their system's efficiency (see also 5.1.9).

Figure 5 - Maintenance of a compressed air system at Porsche (Copyright Druckluft Effizient)

Case history

Optimising the compressed air supply of a car maker

Description

In 1997 the compressed air system of Plant 2 of German car maker Dr. Ing. h.c. F. Porsche AG in Stuttgart was made up of a water-cooled screw compressor (22.2 m^3/min free air delivery, FAD) plus four water-cooled piston compressors of 15 m^3/min each. Maximum operating pressure was 8.7 bar. Specialists from a compressor manufacturer staged an analysis of compressed air requirements, which showed the demand for compressed air varying from 15 to 65m^3/min. After processing all relevant data with the compressor manufacturer's energy saving system, a new compressed air system with optimised energy utilisation was designed.

Action taken

The new system was fitted in two stages, comprising only air-cooled screw compressors. Peak loads were catered for by three machines with an FAD of 5.62 m^3/min each, while four compressors with an FAD of 16.4 m^3/min each provided the base load. All seven compressors were co-ordinated depending on their relative workload by means of a compressed air management system.

Result

Optimising the compressed air system has led to a clear cost and energy saving. Thanks to better utilisation of the compressors, and to being able to lower the maximum operating pressure from 8.7 to 7.5 bar, the specific overall power rating of the compressor station was reduced from 8.19 to 6.19 kW/(m^3/min). The overall savings amounted to 483 000 kWh less electricity per year plus, of course, roughly €55 000 savings per year by reducing the need for cooling-water. Therefore optimising the compressed air system has paid off very reasonably.

Pump systems

Pumps are machines with rotary blades used to maintain a continuous flow of liquids. There is a very wide range of pumping applications, from industrial dishwashers to large pumps in the cooling circuit of a power station. This wide use produces a broad spectrum of available pump types.

Improving the efficiency of pump systems is achieved mainly by selecting the correct pump for the application and working conditions.

Important factors are:

- the design of the section head of the pump
- the pump flow
- the design of the pump impeller
- the properties of the fluid
- the motor speed selected

Case history

Energy saving by reducing the size of a pump impeller

Description

A manufacturer used a centrifugal pump to move condensate from a process and return it to a boiler. Operational analysis showed that the pressure generated by the pump was considerably higher than necessary. The high degree of throttling that was needed had led to instability in the system, resulting in mal-operation and high maintenance costs.

Action taken

After discussion with the pump manufacturer, the company decided to trim the diameter of the pump impeller from 320 mm to 280 mm, which allowed the pump to operate without throttling. Reducing the power required by the pump also allowed a smaller motor to be fitted, which produced further energy savings.

Results

The measures taken eliminated the instability (cavitation) and resulted in significant energy savings. The power consumption of the pump after impeller trimming fell by nearly 30%. Analysis showed that the energy saved by trimming the impeller was 197 000 kWh/year, resulting in an annual saving of €12 714. In addition, an annual maintenance cost of €4 285 due to the cavitation of the pump was saved. The smaller impeller allowed the 110 kW motor to be replaced by a 75 kW motor. This smaller motor, operating closer to its peak efficiency, produced additional savings of €1 071. The work involved in uncoupling, stripping, and rebuilding the pump was modest and machining the outside diameter of the small impeller was a simple job. The cost to trim the impeller was €371. Replacing the 110 kW motor with a new motor of 75 kW required an additional investment of €3 600. Reducing cavitation at the throttling valve also reduced excessive vibration and unacceptable noise.

Profitability

The overall combined pay-back for both the impeller trim and motor size reduction was calculated to be 11.4 weeks. The annual savings were €18 070 on a total investment of €3 971.

Fan systems

Fans are machines with rotary blades used to maintain a continuous flow of gas, typically air. The most common types are the axial and the centrifugal fan.

They range from very small ones used to cool the electronic components of computers, to very large ones such as combustion air fans used in power stations.

The opportunities for reducing energy consumption of fan systems, in addition to the application of HEMs and VSDs, are summarised as follows:

- choosing a high efficiency fan, primarily influenced by blade geometry and casing shape
- designing the ventilation system for minimum loss during the required duty. This should include the length and position of ducts, type of regulation devices and a variable direction or cross-section.
- choosing the best fan for the application
- choosing the best type of control to regulate the fan's speed and cross-section.

A case history

Control of process ventilation

Description

A workshop used a number of process air suction fans to reduce the concentration of airborne particulates and chemicals to improve worker safety. The fans were equipped with manual on/off switches. However, worker self-discipline was poor in turning off the units after use or at the end of the working day.

Action taken

The units (20 in number) were equipped with timers that automatically shut them off after a pre-set delay and at the end of the working day.

Results

Electricity consumption was reduced by 280 MWh/yr, which gave a saving of €12 800 per year. In addition, heating consumption was reduced by 350 MWh/yr, which gave an additional saving of approx. €10 500 per year. The total investment was approx. €9 600.

Profitability

The pay-back time was approximately 0.4 years.

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Annex III: Notes

1 EU-25 = the new, extended Union of 25 countries (including Poland, Czech Republic, Slovakia, Hungary, Slovenia, Estonia, Latvia, Lithuania, Malta and Cyprus)

EU-15 = the current European Union (Austria, Belgium, Denmark, Finland, France, Germany, Greece, Ireland, Italy, Luxemburg, Netherlands, Portugal, Spain, Sweden, UK.

2 The industrial energy consumption does not include transport, tertiary sector, district heating and residential consumption. The tertiary sector uses many motor systems due to the use of fans and pumps in HVAC systems. The total electricity consumption in the tertiary sector in the EU-25 was 652 billion kWh in 2000 [6].

3 It is interesting to look at the perspectives for the year 2020. Indeed, energy policies are made based on long-range projections. Building new power stations, as well as introducing successful energy savings programmes, takes several years. The report 'European energy and transport - trends to 2030' [6] estimates the industrial energy consumption in the EU-25 by 2020 to be 1 432 billion kWh. If the percentage of industrial motor systems' consumption, compared to the total consumption, remains the same, those systems are expected to use 859 billion kWh by 2020 if no action is taken. If, by then, the EU attains all the economically efficient energy savings on those motor systems, the result would be an annual saving of 270 billion kWh (31% of 859 billion kWh), equivalent to the total electricity consumption of Spain in 2000.

4 Efficiency values for pumps should normally be given as a range. Hence, a standard pump would have an efficiency range between 30 and 80%. A high efficiency pump would have an efficiency range of 60 to 88%.

5 Savings potential for systems in the table below does not include potential for high efficiency motors and variable speed drives.

System	Savings potential on the application side (billion kWh)	Present electricity use in industry (billion kWh)
Compressors	23	80
Fans	18	100
Pumps	42	212
Other systems	29	222
Total	+ 112	614

Table 4 - Savings potential for motor driven systems - source: SAVE studies, 2000 [1-5]

Savings potential of other systems assumed to be 13%, a conservative figure (for other systems, potential is 18-29%).

EU-25 figures estimated based on a 12% increase in industrial electricity use with 10 new member states [6].

The national savings potentials for high efficiency motors and variable speed drives for Germany, France, Italy and the UK are estimated by subdividing the EU-15 figures with the same factors as for the application part of the motor systems.

6 Report [18] states absorption figures for an average European forest are between 0.49 tCarbon/ha-yr and 1.4 tCarbon/ha-yr, with a preference for 0.6 tCarbon/ha-yr (p 30). One tonne of carbon is equivalent to 3.67 tonne of CO_2 and 100 hectare is 1 square kilometre. A small calculation gives the absorption of CO_2 per square kilometre per year:

$3.67 \times 0.6 \times 100 = 222$ tonne CO_2/km^2
So 79 million tonne of CO_2 a year is equivalent to the absorption of 355 500 km^2 average European forest (the surface of Finland = 338 000 km^2).

Regarding solar photo voltaic, 'typical' figures are assumed for Europe:
solar irradiation = 1 kW/m^2
availability of solar energy = 1 000 hours/year
conversion efficiency to electricity = 10%

Hence, electricity generated = 100 kWh/year per square metre
Assuming 5 square metre per roof, 362 million solar roofs are required to generate 181 billion kWh.

[7] CO_2 equivalent (CO_2eq) is a metric measure used to compare the emissions from various greenhouse gases based upon their global warming potential (GWP). Carbon dioxide equivalents are commonly expressed as 'million metric tonne of carbon dioxide equivalents (MMTCDE)'. The carbon dioxide equivalent for a gas is derived by multiplying the mass of the gas (in tonne) by the associated GWP:

MMTCDE = (million metric tonne of a gas) x (GWP of the gas)

For example, the GWP for methane is 21 and for nitrous oxide 310. This means that emissions of 1 million metric tonne of methane and nitrous oxide are equivalent to emissions of 21 and 310 million metric tonne of carbon dioxide respectively.

http://glossary.eea.eu.int/EEAGlossary/C/carbon_dioxide_equivalent

The average CO_2eq emission factor for EU-15 is 0.435 kg/kWh. For the ten accession countries it is 1 kg/kWh. For Germany it is 0.638 kg/kWh, UK 0.510 kg/kWh, Italy 0.495 kg/kWh and France 0.083 kg/kWh (values given for 1999).

[8] NO_x is not a greenhouse gas. It should not be confused with N_2O, which is indeed one of the greenhouse gases.

[9] European Commission - JRC, the ExternE project, http://externe.jrc.es

[10] External costs of electricity generation for various fuel cycles: all figures in eurocent/kWh, (n/a in the table below means not available).

Fuel	Eurocent/kWh			
	Italy	Germany	France	UK
Oil	5.6	5.1-7.8	8.4-10.9	n/a
Gas	2.7	1.2-2.3	1.9-3.1	1.1-2.2
Hydro	0.3	n/a	n/a	n/a
Coal	n/a	3.0-5.5	6.9-9.9	4.2-6.7
Biomass	n/a	2.8-2.9	<0.1	<0.1
Wind	n/a	<0.1	n/a	0.1
Nuclear	n/a	0.4-0.5	n/a	n/a
Photo voltaic	n/a	<0.1	n/a	n/a

No external cost estimates are available for electricity generation in the accession countries, but it is carbon intensive and heavily based on coal. Hence, using the EU-15 average to extrapolate to EU-25 provides a conservative estimate.

[11] Electricity prices to industry [19]. In this paper, an EU average price of 5 eurocent/kWh is used.

Country	Electricity prices to industry (eurocent/kWh)		
	2000	2001	2002
France	3.9	3.9	3.9
Germany	5.3	4.4	4.0
Italy	9.7		
UK	3.7	3.5	3.4

[12] The 'power generating capacity' is the maximum capacity of power stations, calculated in Watt. To know their annual production in Wh, this figure should be multiplied by the calculated number of full load operating hours. According to [19], the average European power station is running 4 500 hours a year. So producing 1 billion kWh of electricity a year requires on average a 220 MW capacity. In other words, 202 billion kWh of energy savings makes 45 000 MW (45 GW) capacity unnecessary.

[13] According to IEA Electricity Information 2003, the European Union generated 27.2 billion kWh of electricity in 2001 using 17 GW of wind capacity, i.e. 1.6 GWh per MW installed. Overall electricity production, including conventional power stations, amounted to 2 477 billion kWh using 549 GW capacity, 4.5 GWh per MW installed. Hence, 1 MW conventional power is equivalent to 2.8 MW wind power. Therefore, 45 000 MW of conventional capacity is equivalent to 126 000 MW of wind capacity. According to the European Wind Energy Association (www.ewea.org), a total of 25 000 MW of wind was installed in Europe by June 2003, generating 40 billion kWh of electricity per year, when using the IEA average of 1.6 GWh per MW installed.

[14] For example NEMA Premium Efficiency, Motor Decisions Matter (www.motorsmatter.org), US Compressed Air Challenge, Motor Systems Initiative of Consortium for Energy Efficiency.

[15] A 202 billion kWh energy saving converts to 17 million tonne oil equivalent (Mtoe). Assuming an average conversion efficiency of European power plants of 40%, this converts to a primary energy equivalent of 42.5 Mtoe, or 3% of Europe's primary energy consumption [20]. Since Europe imports about half of its primary energy, this reduces imports by 6%.

[16] IPPC is based on the principle of the 'best available technology'. The European IPPC Bureau sets out definitions of those 'best technologies' in the BREF documents that exist for each industrial process in each industrial sector. By creating an Energy Efficiency BREF document, the energy efficiency of motor systems would be integrated into this licensing system.

[17] COM 2003 (739) Final, Proposal for a directive of the European Parliament and of the Council on energy end-use efficiency and energy services.

[18] http://energyefficiency.jrc.cec.eu.int/eurodeem/index.htm

[19] http://www.lcc-guidelines.com

[20] http://energyefficiency.jrc.cec.eu.int/motorchallenge/tools.htm

[21] http://www.gefweb.org

[22] http://www.cda.org.uk/megab2/elecapps/casestud/index.htm

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