Compressed Air System Audits and Benchmarking
Results from the German Compressed Air Campaign "Druckluft effizient"

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Summary
The electricity consumption for compressed air applications totals approx. 14 TWh per year in Germany and 80 TWh in the EU. An EU study was able to show that economic energy saving potentials of more than 30 % exist which, in Germany alone, correspond to the output of 2 coal-fired power stations or a total amount of electricity of approx. 5 TWh. It is the objective of the campaign "Druckluft effizient" to activate these saving potentials. A large share of these potentials should be achieved by the end of 2004 using a wide variety of activities. Among others, the campaign offers compressed air benchmarking and a free compressed air audit campaign. The aim is to show companies the saving potentials not just qualitatively but also quantitatively. Publishing the results should encourage the implementation of measures in other companies of various sectors. This paper describes the procedure and the results of the measurement campaign, which is accompanied by an evaluation process. The saving potentials determined lie between 10 and 65 % and it was ascertained that, in many cases, savings could already be identified during an on-site inspection even without measurement devices. The Benchmarking, started at the end of 2003 helps to clarify short comings in compressed air systems. However the quality of the output of such an approach is dependent on the widely acceptance of submitting own data to a neutral institution caring for the data.

Keywords: Compressed Air, Energy Efficiency, Audit, Benchmarking, Cost savings, System optimisation, CO_2 emission reduction, awareness campaing.

1 INTRODUCTION

Electricity consumption in industry and the tertiary sector is closely linked with the use of electric motors as drive units in countries of the European Union and world-wide. Estimations for the EU assume an electricity consumption of approx. 800 TWh for motor applications. The main points of consumption in this field are compressed air production, fans and pumps. In all three areas of application there are large energy saving potentials which, in most cases, can be realised economically, even at the currently low electricity price [1]. *The Druckluft effizient* campaign is based on the results of the compressed air study for the European Union which was headed by Fraunhofer ISI [2]. The structure and the different activities of the German Campaign have already been presented elsewhere [3, 4].

In spite of the economic efficiency of measures in the field of compressed air production, in practice there is still an implementation deficiency even though the measures usually have a higher profitability than investments in other sectors. The reasons for this are, among others:

- The electricity consumption in compressed air systems is frequently invisible for management since it has often only a small share in total costs.
- The electricity consumption and especially the electricity consumption in compressed air systems is frequently accounted for under overhead costs in the companies. For this reason, there is usually no-one directly responsible for these costs.

- Measures to optimise procurement costs are mostly oriented towards investment costs for the systems and not operating costs. However for compressed air systems usually more than 75 % of the life-cycle costs are accounted for by energy consumption whereas investments have only a small share in life-cycle costs.
- The responsibility for compressed air systems is usually spread over several management functions (production, maintenance, procurement, accounting). It is often difficult to reach a general agreement in an area with low priority.

Since the obstacles to realising energy efficient measures mainly relate to organisational factors among compressed air users, the measures possible should be oriented to users and target organisational changes. The objective is to convince management (executives and directors) to make the necessary decisions for carrying out energy efficiency programmes.

2 COMPRESSED AIR SYSTEM AUDITS

While the significance of energy costs in the total costs can be clearly shown with the help of the life cycle cost approach, this still does not indicate any starting points at which concrete energy conservation measures should be applied. Here, each individual system has to be subjected to a detailed analysis which can usually be done at a manageable cost. Within the scope of the measurement campaign of *Druckluft effizient*, Fraunhofer ISI coordinated the Audits conducted by the project partners Atlas Copco, Boge, Gardner Denver Wittig, Gasex, Ingersoll, Kaeser, Systemplan Karlsruhe and Ultra Air. However the work of the project partners (making the measurements and data collection, preparing a first draft of the audit report) was supervised by Fraunhofer ISI to secure a high quality and neutrality in the recommendation on how to improve the analysed systems.

2.1 Selecting Companies to receive free compressed air audits

Companies interested in participating in the free measurement campaign had to send initial data about their compressed air system in a preliminary questionnaire . Information about the compressor (type, manufacturer, pressure, output, power, control, annual load and no-load time), the distribution system (length of network, pipe diameters, receiver size, pipe material and types of connection) as well as the air treatment (drier type, filter, condensate treatment, required quality under DIN/ISO) have been requested from the companies among other information. Data about sector affiliation, turnover and the number of employees were also requested to help guarantee the transferability of the results from one company to other comparable ones. Most of the returned questionnaires were satisfactorily completed, in some cases however there were incorrect data on, e.g. compressors; some units were not considered or the classification did not match the given information on performance. These data were imported in an excel summary file and anonymized for selection.

Criteria for the selection included the estimation of compressed air experts with reference to possible savings, an even spread of measurements according to system size (kW installed), type (screw, piston, turbo other), sector affiliation and the investments planning. Companies to be given a measurement received confirmation and a suggestion as to which company should conduct the measurements. The companies were then able to request an alternative which was taken into consideration if possible, but this only occurred once. All other companies received a rejection or were referred to the following selection round for which positively assessed companies automatically qualified.

The project group *Druckluft effizient* selected on this basis 80 companies to receive a free compressed air audit.

2.2 Assessment of the applications received

At the end of the selection period in 2002 there were a total of 190 applications from companies. **Figure 1** shows how the applications are split according to the total capacity of the compressed air systems.

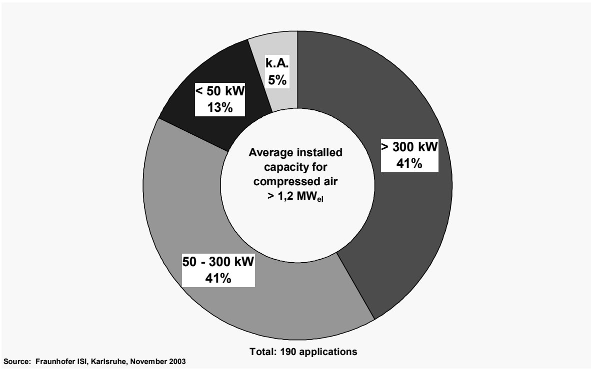

Figure 1: Split of applications based on system size

More than 80 % of all applicants own compressed air systems with an installed power of more than 50 kW, only 13 % have systems with less than 50 kW. The applications ranged from 1.5 kW up to 22.9 MW. This has been expected since the absolute saving potentials are limited in systems smaller than 50 kW, although the relative saving potentials do not differ from those of large systems. It is more surprising that 41 % of the applicants own systems with a power of more than 300 kW. This share was even larger at the beginning of the measurement campaign, a clear indication that companies with large compressed air systems are more likely to have personnel whose main job is compressed air supply and who also have the time necessary to obtain information about energy saving measures.

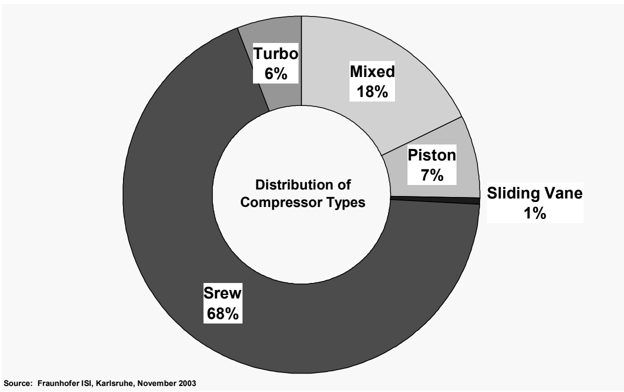

Figure 2: Distribution of Compressor Types

The applications originated from 32 different sectors ranging from the food industry, metal production to applications from research and health care. Most applications came from industrial branches in which compressed air plays an important role. These include the chemical industry, manufacturing of metal products, vehicles and the food industry. Those industrial branches in which compressed air is of above average importance (food industry), or in which there is strong competition (vehicle production), showed particular higher interest. **Figure 2** shows the distribution of compressor types. Based on the large installations, the share of turbo-compressors was over represented under the applicants.

3 WHAT CAN BE LEARNT FROM THE AUDITS

It was an important objective of the measurement campaign to move away from the component approach to a system approach. This was based on the fact, that the EU Study on compressed air systems has pinpointed, that the saving potential at the component level is rather small compared to the potential at the system level. The audits at system level included therefore the ventilation of the compressor room, the drying of the compressed air, the controls, codensate removal and treatment, the filters, the distribution and to some extent also the application involved. To determine the compressed air amounts, thermal volume flow measurement and digital calculation of the running time were used. It must be taken into account that, in the first case, the volume flow is typically given in standard cubic metres and, in the second case, in normal cubic metres. These two values differ by about 10 % since the under-lying temperature and pressure of the volume flow are different. People in the field can therefore easily be confused, as typically only volume flow are given without the associated pressure and temperature. In addition typically pressures are given as bar exceeding pressure instead of total pressure. Pressure measurements were made at different locations of the distribution network, sometimes electrical power consumption or compressed air consumption of individual plants have been measured. The measurements usually took place over 7 to 10 days so that in each case the measurement period included a weekend.

Information was also requested on known disturbances, costs for repairs and maintenance as well as the time involved for system supervision by company staff. However these data where often difficult to obtain, as companies do not have this data at hand. At an initial interview with the company, a first inspection of the firm and the compressed air system was also conducted to gain an impression of the actual situation. During this inspection, the measurement points were agreed with the company and, where necessary, any preparatory work to be done by the company was discussed, e. g. providing a power supply or fitting ball valves for the necessary measurement sensors. Some optimisation potentials were already able to be identified during this inspection by the compressed air experts, for example missing cyclone separators behind the compressors and filters and cyclone combinations installed in the wrong order (the filter should always be installed behind the cyclone). To some extent, even leaks at the dryer flange could be ascertained which could easily be eliminated.

These inspections were made by different project partners. They have been strongly advised to give company-neutral informations. By randomly taking part at the initial interviews, Fraunhofer ISI supervised the measuring companies. Of course it always has to be considered that the quality of the advice depends on the qualification and motivation of the adviser. Also the final report had to be submitted to Fraunhofer ISI, who checked, extended and corrected the reports if necessary together with the measuring company, before the report was sent to the company.

3.1 Results from inspections

In many cases potentials for optimisation have been found without measurements just from the inspection of the companies' compressed air systems and production plants. Some examples are shown in the photos below. The selection is relatively random and does not claim to present all the shortcomings. In almost every case the situation arose due to necessary alternations. These potentials for optimisation are frequently not sufficiently considered or not recognised by staff due to the lack of awareness of the costs of compressed air in the companies. This is the strong point of an experienced compressed air specialist who can often perceive these shortcomings during the first inspection.

Case 1: the cooling air opening for the compressor was set according to the manufacturers specifications. Due to the high particle content in the environment, a bag filter was then fitted later. This successfully solved the problem of the particles but the supply of cooling air is no longer large enough because the bag filter reduces the area of the cooling air opening, so that the temperature in the compressor room became clearly too high, **Figure 3**.

Case 2: there was only room for the compressor between other systems due to several changes to the production plant and the extension of the compressed air supply. At this position, however, there were no supply or discharge air ducts. The compressor was therefore not connected to the air ducts. Some of the compressor's openings were additionally covered by a piece of wood for no reason, **Figure 3.**


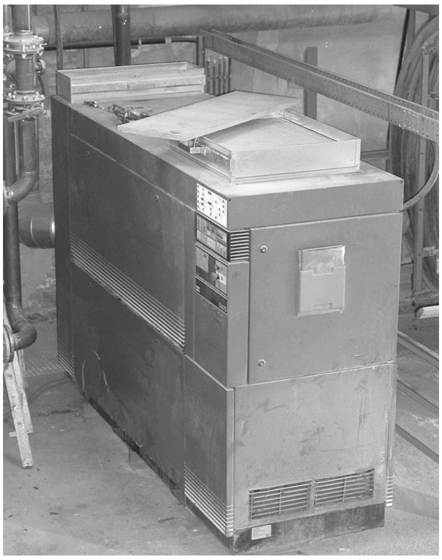

Figure 3: Case 1 (left) and Case 2 (right)

Case 3: the company needs compressed air to transport material from external silos. During the winter months there were repeated discharge problems since the refrigerated dryer could not ensure sufficient dehumidification of the compressed air. An additional adsorption dryer was fitted for this partial flow. It was set to –50 °C to be on the safe side and runs in the summer months with this dew point as well although this is not necessary, **Figure 4**.

Case 4: the compressor room of the company is fitted with directly adjacent supply and discharge air openings. This situation is unsatisfactory but in addition it was ascertained and confirmed by the company that vehicles and lorries are usually left in this area and supply and discharge air are thus short-circuited, **Figure 4**.

Case 5: spiral hoses were once used to connect the tools to the compressed air mains. These were later replaced by automatic winders. The spiral hoses now serve to connect the winders to the air mains. A straight hose with much lower pressure losses would clearly be the better choice here, **Figure 4**.

Figure 4: Case 3 (left), case 4 (middle), case 5 (right)

Case 6: Filters and cyclones look very similar from outside (cyclones are typically smaller). However they have different functions. The cyclone should separate the water droplets, the filter the particles out of the compressed air. If the filter is however installed before the cyclone, there will be no more work for the cyclone. Instead the water will quickly impede the pressure loss across the filter and the cleaning capacity. **Figure 5**.

Figure 5: Case 6

3.2 Results from measurements

After the measurements have been completed, the measurement company compiles a report using the measurement data which includes the description of the actual situation and a set of measures to optimise the compressed air supply. The report is relatively detailed and describes the specific important results. All the results are described in anonymous form, i.e. the company name is not mentioned. Only those in charge of the project and the company doing the measurements are able to de-anonymise the report.

In the measurement campaign it was shown that the multistage procedure when conducting the campaign permitted good quality control, but also resulted in several delays due to the large number of measurements made with limited personnel capacity.

3.2.1 Measuring air leakage rates

Determining the amount of leaks is usually done by timing the compressors operating intervals while the system is shutdown. The quantity delivered during shutdown corresponds to the amount of leaks, although it must be taken into account that small consumers such as the control of air conditioning may be assessed as leaks. Since most leakage's occur in the last third of distribution, especially in the machines, it is helpful to record the leakage separately for different areas. This can be done by opening the ball valves of individual machines and work areas one after the other, see **Figure 6**. M1 to M8 denotes to 8 similar production lines, showing quite different leakage rates.

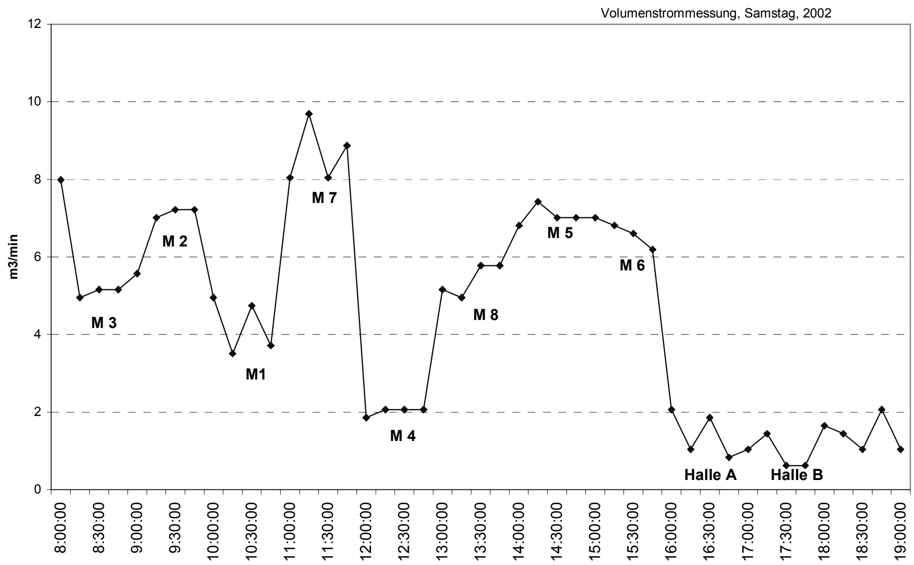

Figure 6: Measuring leaks during system shutdown and opening the slide valves of individual machines and works' areas

3.2.2 Determining the no-load share

The following example shows poor utilisation of a compressor system. F**igure 7** shows the measurement of the volume flow rate in this company over one week. At the weekend during shut-down, the leakage of compressed air equals approx. 25 l/s. This is equivalent to a share of approx. 19 % leaks based on the average consumption.

Table 1 summarises the technical data of the compressed air system of this company as well as the load data of the compressed air system. The three compressors work in a pressure band from 6.5 to 7.5 bar_e. The pressure band could be reduced to approx. 0.5 bar using an appropriate control which would save energy. At present, the compressors are switched in succession 3 – 2 –1 , i.e. Compressor 3 operates as the base load machine. With a load time of 81.4 h in the period reviewed it has the largest number of operating hours. As well as the load time, the compressor is also 56.2 h idling, consuming approx. 30 % of the rated power without supplying compressed air at that time. The no-load share for this compressor and compressor 2 totals 40 %, compressor 1 even has a no-load share of 81.3 %, although the absolute number of hours is small. Overall, approx. 17 % of the total electricity consumption for compressed air production are accounted for the idle running of the compressors. Measures to reduce the no-load losses would be the use of a speed-controlled compressor which could almost entirely reduce the no-load loss or a better selection of the compressors proportional to the predominant consumption conditions.

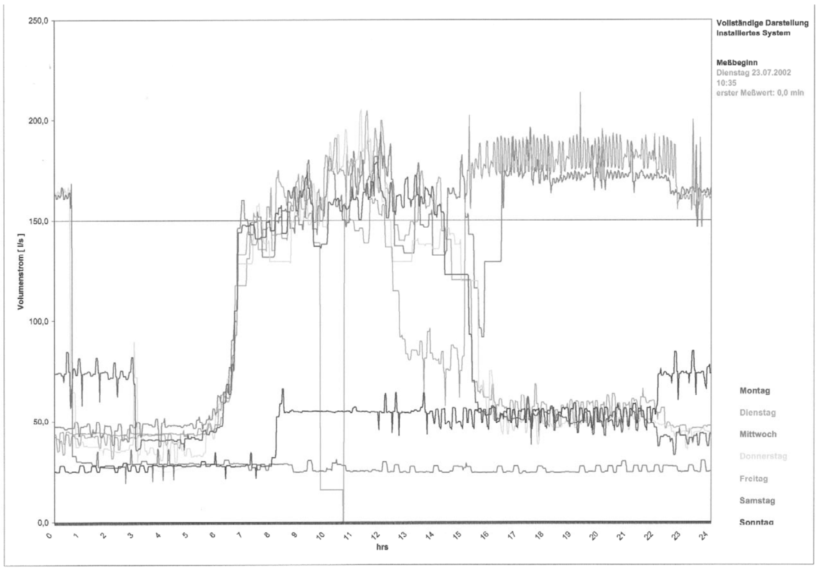

Figure 7: Measurement of the compressed air volume flow rate (normal cubic metres) over one week

Table 1: Technical data of the compressor system

Remarks		Start of compressed air measurement				23.07.2002 10:35 Uhr	
		End of compressed air measurement				30.07.2002 9:45 Uhr	
		Operating pressure [bar]:				6.5 bar bis 7.5 bar	
		Receiver [Liter]:				3000	
		Number of receivers:				3	
		Compressor 1		Compressor 2		Compressor 3	
Year of Construction		1991		1989		1989	
FAD		81.0 l/s	4.86 m³/min	128.0 l/s	7.68 m³/min	125.0 l/s	7.50 m³/min
max. pressure		7.5 bar		10.0 bar		10.0 bar	
pressure band setting [bar]		7.1 bar to 6.5 bar		7.3 bar to 6.8 bar		7.5 bar to 7.0 bar	
Rated power		30.0 KW		55.0 KW		55.0 KW	
Current consumption Full load	No-load	33.8 A	7.8 A	79.6 A	17.2 A	92.7 A	19.8 A
Voltage		400V		400V		400V	
Lagging time	Starts / Hour	360 sec		20 sec	10 /h	360 sec	
Operating data Operating hours / Full load hours		40 h	..—..	43 h		137 h	....—
Full load- / No-load		7.6h	33.1 h	26.1 h	17.2h	81.4h	56.2h
Stopping hours		127.3h		124.6h		30.4h	
Compressor load factor		4.5 %		15.5%		48.5 %	
No load share		81.3 %		39.7 %		40.8 %	
Load factor compressed air system		22.8%					

The results illustrated here are only a small excerpt from the examinations conducted as part of the free measurement campaign. As well as the compressors, the compressed air treatment, condensate treatment and air distribution were subjected to a detailed analysis.

4.1 Overall results from the Audits conducted

Based on the results of the audits conducted, a generalised analysed has been performed to better understand the linkages between different factors and to identify sectors of industry in which more work needs to be done to activate the economic saving potentials.

As a first step to do so, the specific saving potentials have been drawn against the number of employees and the compressed air electricity consumption, **Figure 8.** Both diagrams show a clear trend of larger saving potentials in small companies and companies where compressed air is of less importance. However the variation of results is rather large and was not expected in such a way. The efficiency of the compressed air system is therefore dependent on the individual person responsible for the plant and / or the overall company philosophy related to energy and environmental issues.

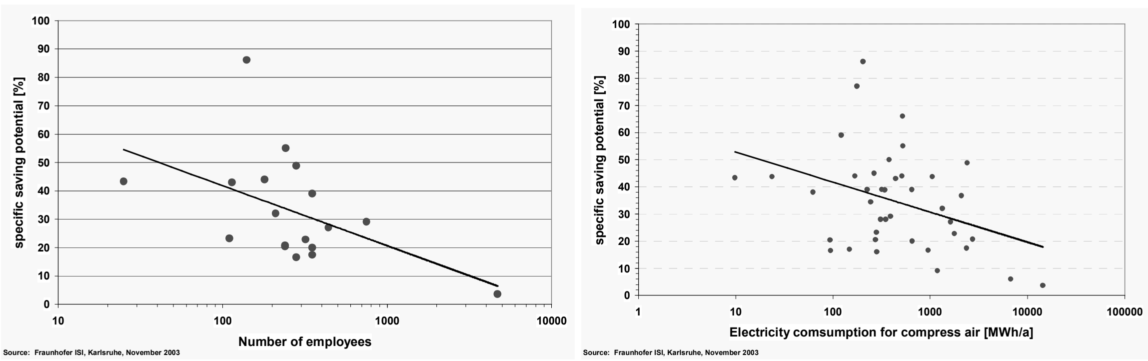

Figure 8: Specific saving potential in compressed air systems compared to the number of employees and compressed air electricity consumption.

To get further inside which companies may have the largest total saving potential, the total cost savings where plotted against the specific energy savings, assuming that companies with higher specific saving potentials will have higher cost savings. However the results showed that this assumption seems to be not true, instead the total cost savings are slightly decreasing with increased specific saving potential, **Figure 9**. Based on the results it can be stated, that the savings for each company, independent of its size seems to be between 10 and 20 000 Euro, but again with a very large variation. This may result as a fact that only economic improvement potentials (pay back below 3 years) have been taken into account, therefore in most companies only the low hanging fruits will be picked.

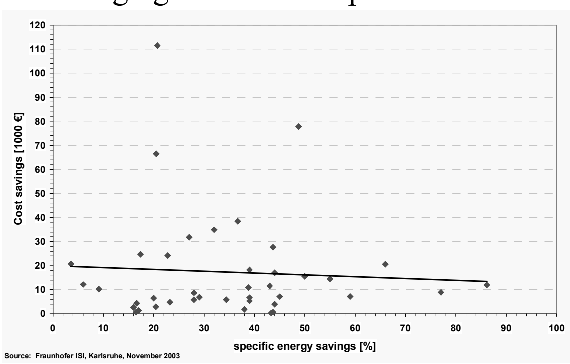

Figure 9: Cost savings and specific saving potentials

It might be also of interest to analyse the different sectors of industry. However as the number of sectors to be covered is large compared to the total number of audits performed, the significance of the results (standard deviations) is small. The highest saving potentials above 60 % have been identified in the sectors Non Metallic Minerals (Nace 26), Fabricated Metal Products (Nace 28) and Electrical Machinery (Nace 31). The lowest potentials have been found in the sectors Chemicals (Nace 24), Basic metals (Nace 27) and Motor vehicles (Nace 34), **Figure 10**. If the results of all companies taking part in the audit campaign are equal weighted, the average economic saving potential encountered is about 33 %, a value which shows a good agreement with the results of the compressed air study for the European Union [2]. If the saving potentials are weighted by the absolute savings obtained, the average value falls to about 20 %, which is still an impressive number. This is mainly due to the fact, that larger installation have typically a smaller saving potential. The overall saving potential in Germany will however be closer to 30 %, as the larger installations included in the audit campaign had a larger share compared to their share on the German market.

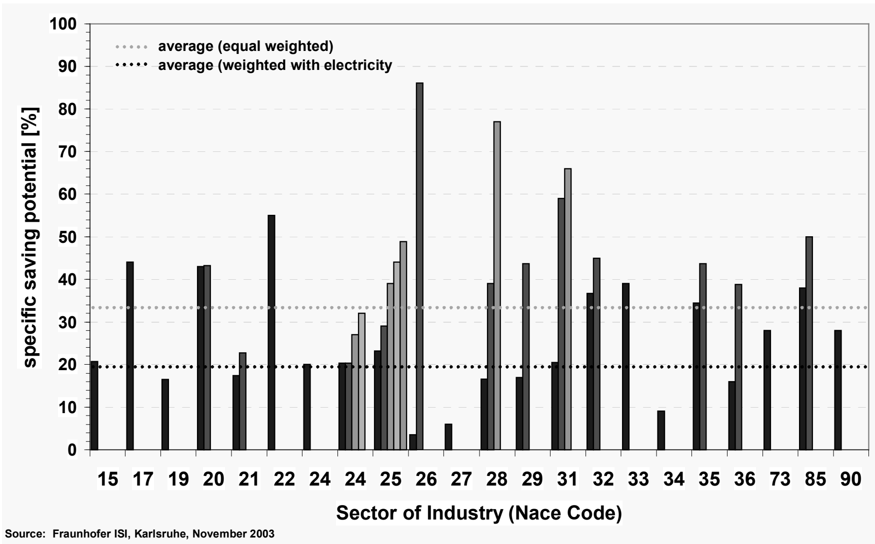

Figure 10: Saving potential by sector of industry and average potentials for industry.

If the saving potentials found in the audit campaign are projected to the 50000 German companies, the annual economic saving potential in Germany is 2.8 TWh. This would reduce the CO_2 emissions by 1.6 Million Tonnes. The required investments to achieve these savings would be around 126 Million Euro and an additional amount of 28 Million Euro would be required to cover the in house cost for system optimisation. For an average electricity price of 4 ct/kWh the annual cost savings from these measures would be around 110 Million Euro. So the pay back time of the measures will be just a bit over one year.

5 BENCHMARKING

The objective of benchmarking is to allow companies to compare the energetic situation of their compressed air system with the systems of other companies and at the same time to receive feedback about the success of implemented measures. The questions answered include, e.g.

- Is the energy consumption of my compressed air system too high?
- Are the maintenance costs of my system too high?
- Where does my company stand in relation to others from the same sector?

Benchmarks are used for the analysis of production plants. Benchmarks have been used for a long time as an effective instrument in corporate controlling since they compress an extensive amount of data into a comprehensible amount of key information. Benchmarks thus help management make decisions. Companies can then see where they stand in comparison with other companies of a similar production structure. Benchmarking aims at a comparison with the best in the sector in order to become the best and to maintain that position. Since the end of 2003 the campaign *Druckluft effizient* is offering a free compressed air system benchmarking. The idea to start a benchmarking was based on the fact, that most compressed air user are not aware of the cost associated with the use of compressed air and what might be the possible saving potential. To help the compressed air user, the Benchmarking is a two step procedure, starting from the analysis of the indicators of the companies own compressed air system, which are calculated based on the data to be submitted via the Internet and then comparing the own indicators with the indicators of other companies of the same sector. Based on the indicators, first recommendations where given, which might be the reason for a good or poor position compared to the competitors. Up to date, data of about 100 companies are all ready included in the Benchmarking database. However compared to the number of companies in Germany and the number of different sectors present, this amount is still to small to calculate indicators on a detailed sector level, therefore the need to convince additional companies to participate in the benchmarking system is obvious.

To take part at the benchmarking system, companies need to supply data of their compressed air systems (installed capacity, number of operating hours, dew point etc) together with some data on the company such as turnover or number of employees. In the internal Benchmarking the indicators such as the compressors and compressor station load factor (**Figure 11**) and the compressed air costs in ct/m^3 (**Figure 12**) are presented as a time series together with some typical values of these indicators.

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		2000	2001	2002
S40	[%]	k.A.	95,46	83,31
SK 26	[%]	k.A.	38,43	38,43
S-R 1660-35	[%]	k.A.	100,00	100,00
S-R 1660-35 b	[%]	k.A.	100,00	100,00
VLEX 37 R 9	[%]	k.A.	77,67	77,67
Gesamtauslastung	**[%]**	k.A.	**62,72**	**59,17**

Figure 11: Load factor of single compressor and compressor system

In the second step, the company specific indicators are benchmarked against the data of other companies. Depending on the indicator and the amount of benchmark data available, the comparison is made on the sub sector, sector or all sectors of industry. **Figure 13** gives an example of the benchmark data for the average age of the compressors installed. The own data are given in red, data for other companies in blue. The mean value of compressor age has been calculated to be 11.3 years. The mean value of the best companies (values above the average) is much lower and has been calculated to be five years. In total a set of 20 different indicator is calculated and compared for each company, when all required data are submitted. Dependent on the results of the benchmark, some possible improvement potentials are pointed out. However this advice is not foreseen or able to replace an detailed analyses of an compressed air system audit

Figure 12: Cost factors of compressed air generation

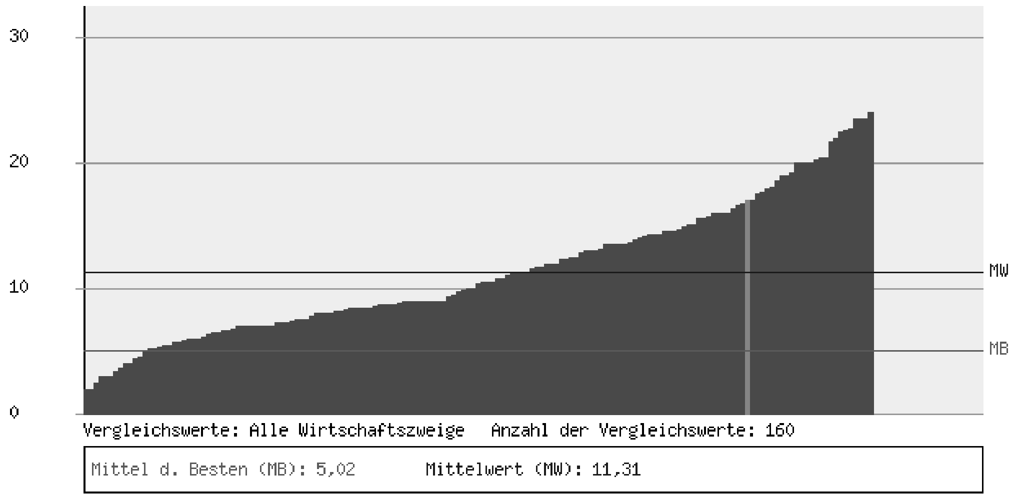

Figure 13: Average age of compressors

6 SUMMARY

Energy savings of approx. 2.8 TWh should be activated in the next few years as a result of the campaign *Druckluft effizient* in Germany. Expressed in terms of the reduction of CO2 emissions during electricity production, approx. 1.6 million tonnes CO_2 can be avoided alongside with an energy cost saving of approx. 110 million Euro in energy costs result for the companies involved. The free audit campaign has been a first step to realise these savings. The results of the measurements clearly prove the existence of large saving potentials in companies. The first results of the compressed air benchmarking are encouraging, but the value could be further improved with each additional company taking part in the benchmarking process.

Based on the positive findings and results achieved in Germany so far, it is recommended that other countries start also similar activities in compressed air systems. At the time this is already the case in Switzerland and we hope that other countries will follow the German example.

Druckluft effizient
The campaign is conducted by the German Energy Agency (dena), the Fraunhofer Institute Systems and Innovation Research (Fraunhofer ISI, project management), and the Federation of the Engineering Industries (VDMA) with the support of the Federal Ministry for Economics and Labour (BMWA) and the following industrial enterprises: Atlas Copco, BEKO Technologies, BOGE Kompressoren, domnick-hunter, Energieagentur NRW, Gardner Denver Wittig, GASEX, Gebr. Becker, Ingersoll-Rand, Kaeser Kompressoren, Legris – TRANSAIR, METAPIPE, Schneider Druckluft, systemplan Karlsruhe, ultra air, ultrafilter International and ZANDER Aufbereitungstechnik.

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