Comparing Efficiency: Internet-Based Benchmarking for Compressed Air Systems

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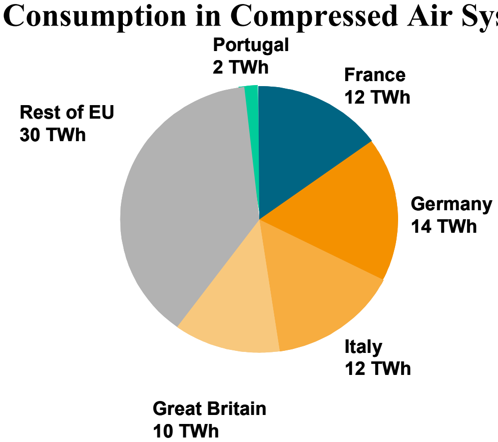
ABSTRACT

Many studies in the EU and the US have revealed the large potential for energy saving in compressed air systems. However, this potential is often not taken seriously by industry, as managers often feel that they are able to maintain and operate their system efficiently. The high entry price for measurement-based analysis of compressed air systems, together with the lack of information on benchmarking values, represent a strong barrier to optimizing compressed air systems. The Internet-based compressed air benchmarking system developed within the German compressed air campaign "Druckluft effizient" has recently successfully removed this barrier by allowing consumers to perform rudimentary analysis using simple measurements they can gather themselves. The paper will explain the set-up of the system and the indicators chosen for comparison. The paper presents initial benchmarking results for a participating company which show how the information from the benchmarking can be used to improve the compressed air system. At the time the paper was written, about 100 companies in Germany were already taking part in the benchmarking. In the near future the system will be extended to include other languages and currencies.

Compressed Air Energy Use and Saving Potential

A study conducted for the European Union in 1999 showed that the annual total energy consumption in the EU-15 for the generation of compressed air was about 80 TWh (Radgen 1999). This is about 10 % of the total electricity consumption in industry. The total consumption by country is therefore largely dependent on the industry structure of each country, cf. **Figure 1**. Germany had the highest consumption in Europe.

Figure 1: Energy Consumption in Compressed Air Systems in the EU-15



Source: Radgen, P., 1999.

Based on different sources, ranging from literature reviews and expert interviews to pilot tests, a set of optimization measures was identified in compressed air systems and evaluated to determine the typical saving potential and the applicability of each measure for compressed air systems in industry. During the course of this study it became obvious that in order to achieve the highest cost-benefit ratio for improvement measures, the optimization of compressed air systems has to involve not only compressors but also the complete process chain of the motor driven system. **Table 1** summarizes the possible savings. As can be seen, leakage reduction is the largest single potential identified. The reduction of leaks in compressed air systems could save 16 % by itself. Other important measures are the use of sophisticated control systems, the application of adjustable speed drives, the overall system design and the use of waste heat.

Table 1: Energy Saving Measures in Compressed Air Systems

Energy saving measure	applicability (1) %	gains (2) %	potential contribution (3)
System installation or renewal			
Improvement of drives (high efficiency motors, HEM)	25 %	2 %	0.5 %
Improvement of drives: (adjustable speed drives, ASD)	25 %	15 %	3.8 %
Upgrading of compressor	30 %	7 %	2.1 %
Use of sophisticated control systems	20 %	12 %	2.4 %
Recovering waste heat for use in other functions	20 %	20 %	4.0 %
Improved cooling, drying and filtering	10 %	5 %	0.5 %
Overall system design, including multi-pressure systems	50 %	9 %	4.5 %
Reducing frictional pressure losses	50 %	3 %	1.5 %
Optimizing end use devices	5 %	40 %	2.0 %
System operation and maintenance			
Reducing air leaks	80 %	20 %	16.0 %
More frequent filter replacement	40 %	2 %	0.8 %
TOTAL			32.9 %

Table legend: (1) % of CAS where this measure is applicable and cost effective
(2) % reduction in annual energy consumption
(3) Potential contribution = applicability * gain

Source: Radgen, 1999

The findings of the study for the European Union formed the starting point for the German compressed air campaign "Efficient Compressed Air." The aim of the campaign was to convince compressed air users to optimize their systems to achieve cost savings, increase the reliability of the system and help reduce CO_2 emissions from the use of electricity. The programme has been targeting users by providing general information on how to improve compressed air systems such as the compressed air fact sheets, which are also available in English on the campaign Website (Druckluft effizient 2003). In addition, the campaign developed a one day training seminar in which more than 700 people from all sectors of industry participated to get the system optimization process started. There was also an audit campaign in which 70 companies received a free and detailed compressed air system audit. Results from this audit campaign have already been reported elsewhere (Radgen 2004a).

A question which arose during the audit campaign concerned the problem of pre-screening compressed air systems to effectively identify the possible improvement potential without investing too much money in measurements. This proved to be a vital question as there were far too many applicants for the free audit. The objective was to help compressed air users improve their systems using very simple measures and to follow up the savings achieved. Benchmarking was identified as one possible measure.

Benchmarking

Benchmarking is the comparison of processes, practices or services in order to create a baseline and identify deficiencies at individual sites. This can be done on a product or service level by comparing costs, quality, efficiency, consumer satisfaction, time to delivery or other indicators judged to be relevant to describe the activity. Benchmarking can compare annual values of indicators within a company, different sites within a company or one company's results with other companies from the same or different sectors. The greater the amount of data for comparison, the more robust the results, so it is important that the maximum possible number of companies participate in the benchmarking activity. Care should be taken that benchmarking is not aimed at identifying "black sheep" but instead at "Best Practices," which will help to bring about a competitive advantage.

Benchmarks have been used for a long time as an effective instrument in corporate controlling since they compress an extensive quantity of data into a comprehensible amount of key information. Benchmarks thus facilitate management decisions. Companies can then see where they stand in comparison with other companies of a similar production structure. Continual controlling is essential to maintain any competitive advantage.

Compressed Air Benchmarking

The availability of compressed air is a prerequisite in almost all companies. Therefore each company operates at least one compressed air system to provide the required air. However knowledge about the system is typically crude. Questions asked which often could not be answered include:

1. What is the energy consumption per m^3 of air?
2. What is the cost per m^3?
3. Would it be possible to reduce the maintenance cost?
4. Am I using the right technology?

To answer such questions a set of indicators need to be defined which can then be used for comparison and to evaluate and improve the situation. A set of 23 indicators was identified for compressed air benchmarking. These indicators cover not only the compressor, but the whole compressed air system, including the air and condensate treatment and the distribution system. **Table 2** gives an overview of the indicators selected to analyse compressed air systems.

Table 2: Compressed Air System Indicators for Benchmarking

compressed air cost per Euro turnover	compressed air cost per employee	compressed air cost per m^3	electricity consumption for compressed air per Euro turnover
electricity consumption for compressed air per employee	cost for electricity consumption per Euro turnover	share of electricity consumption for compressed air in total electricity consumption	specific power consumption for the compressor station
load factors of compressors	specific electricity consumption per m^3 of air	number of malfunctions and repairs per operating hour	average age of compressors
installed compressor capacity per employee	size of storage capacity to installed compressor power	relation between electricity and fuel price	waste disposal cost per m^3 of condensate
average percentage pressure loss in the distribution	maximum velocity in the main line	piping materials used	type of pipe connection used
length of distribution line per installed compressor power	type of dryers used	types of condensate traps used	

Source: Radgen 2004b

Based on the set of indicators identified, the data required to participate in the program are fixed. The data required can be divided into two groups. The first concerns general information about the company such as details of the contact person, the sector of activity and the access data. These data only have to be provided once and need only be updated if changes occur. In addition annual data are required on electricity costs (working and supply charges), turnover, number of employees and other general data which typically change each year.

The second data group is linked to the compressed air system installed. Data on the technical equipment such as the size and type of compressor, the type and capacity of the dryer, the length and material of the piping and other have to be supplied once and are saved. On a yearly basis operating data have to be entered such as the number of operating hours, the dewpoint selected and the number of filters replaced.

The system was designed in such a way that operating data can be given beginning with the year 2000. Trial tests showed that it takes about 1.5 hours to collect and enter all the data required for a period of 4 years and about 15 minutes to update this data for an additional year. However, as the experiences made with the compressed air measurement campaign showed, sometimes not all the data can be provided by the system operator. For example, the number of operating hours at full load often cannot be accurately provided because many compressors only have a counter for the total number of operating hours, which include hours when the compressor is idling. Therefore in some cases, default values had to be used to enable a calculation to be made even where some values are missing.

Implementation of Compressed Air Benchmarking

The benchmarking system should be able to handle a large amount of data and it should be easily accessible to every compressed air user. Therefore the decision to use a web-based benchmarking system was the obvious choice. Data are collected via a web interface and stored in a database. The data of each user are password protected and can only be modified or viewed by the owner. To ensure data confidentiality, the benchmarking indicators are anonymized so that it is impossible to identify the companies which have taken part in the benchmarking. The data are hosted by the Fraunhofer ISI, an independent non-profit research organization.

The analysis of the data was divided into two different stages for the benchmarking process. The first one is internal benchmarking. Here, no reference is made to competitors' data; instead the company's own indicators are analyzed for a period of time beginning with the year 2000 (if the data has been provided). This internal benchmarking enables the user to identify savings achieved by measures already undertaken to improve the system, or to identify significant changes which might be due to faults in the system. For example, if the total air production has risen significantly without a corresponding change in production, this could indicate defective condensate traps or broken distribution pipes which might not have been identified without monitoring the system. In the second stage, external benchmarking compares the company's own indicators with indicators from competitors and presents the results graphically in charts and tables. This external benchmarking can be done for each year independently. In the diagrams, the company's own values are shown in red whereas the data of other companies are shown in blue. In addition the mean value of each indicator is calculated based on all the data available. As benchmarking aims to motivate companies to become the best of the best, the mean of all the indicator values which are greater than the overall mean is also displayed. Upper and lower values are also given for the indicator, so that the user can easily see whether this indicator has a large range or not.

To make sure that results are comparable between different companies, the 4-digit NACE code level is used. However, due to the large amount of NACE codes it cannot be guaranteed at the start that there will be sufficient values available for a useful comparison. In these cases, the system automatically makes the comparison at the level of the group of companies belonging to the same NACE 2-digit group or even taking all data entries into account. In any case, the results clearly state which degree of detail was possible.

It should be noted that the results of the external benchmarking are dynamic and not static like the values from the internal benchmarking. All the available data in the database are used for the external benchmarking. Therefore if additional companies join the benchmarking system, the values of their indicators influence the mean values and might enable comparisons to be made on a much more sector-specific level. As more and more companies participate in the benchmarking, the results become more and more robust.

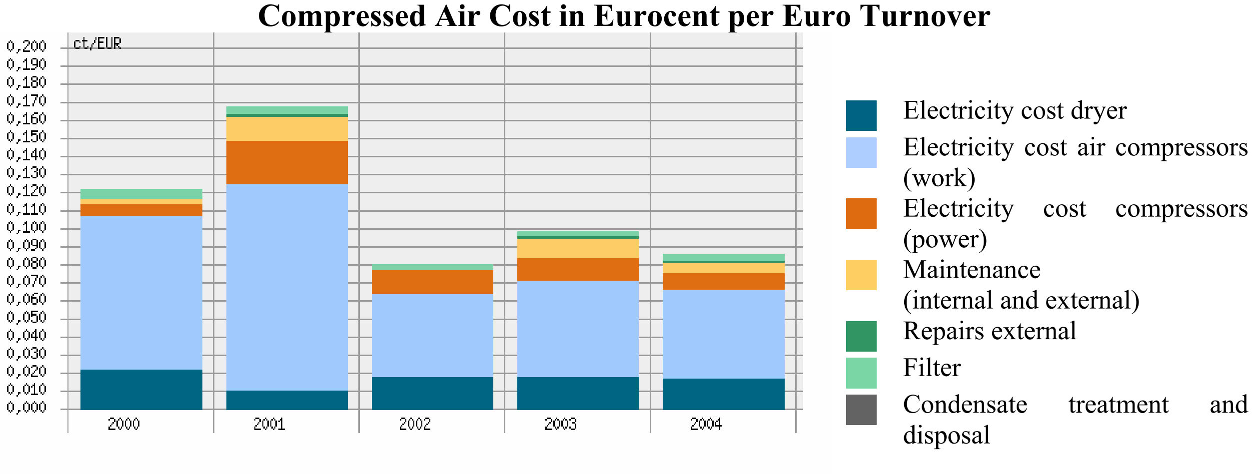
So far the benchmarking system has been developed for the German market. For this reason, the texts are only available in German and the only currency used is the EURO. Due to the high degree of acceptance of the benchmarking approach throughout industry in Germany, the system is now about to be introduced in Switzerland as well. However this requires modifications to the system structure since the system for Switzerland has to be able to handle German, French and Italian and make calculations based on Swiss Francs. At present, the system is being adapted to these new demands. After these adaptations have been made, extending the system to include other languages or currencies should be very straightforward and will mainly require translation work.

Results of the Internal Benchmarking

In the following, exemplary results of the benchmarking for one company are presented. In some cases, the figures are already outdated as the analysis was made using the database version of December 2004. To start with, once the data had been provided, the indicators of the internal benchmarking were calculated and analyzed. Calculating the indicators for the internal and external benchmarking is done on-the-fly, so the results can be shown directly after the data entry has been completed. There is no need to wait and log on to the system later to view the results. However, the benchmarking will only work if companies supply as complete a set of data as possible. Indicators for which the company's own value could not be calculated will not be displayed. This should be seen as an incentive as companies tend to try and take advantage of benchmarking results without revealing their own data.

Figure 2 shows the results for the indicator "compressed air cost in Eurocent per Euro turnover." One explanation for the results is that high-tech sectors typically have lower compressed air costs per Euro turnover than sectors with standard products. It should also be noted that a lower use of production capacities will reduce the turnover but that typically the specific energy consumption still rises which will also show up in a higher cost for compressed air per Euro turnover. A value of 5 Eurocent per Euro turnover can be taken as an upper boundary in industry.

Figure 2: Results of the Internal Benchmarking: Indicator 1: Compressed Air Cost in Eurocent per Euro Turnover

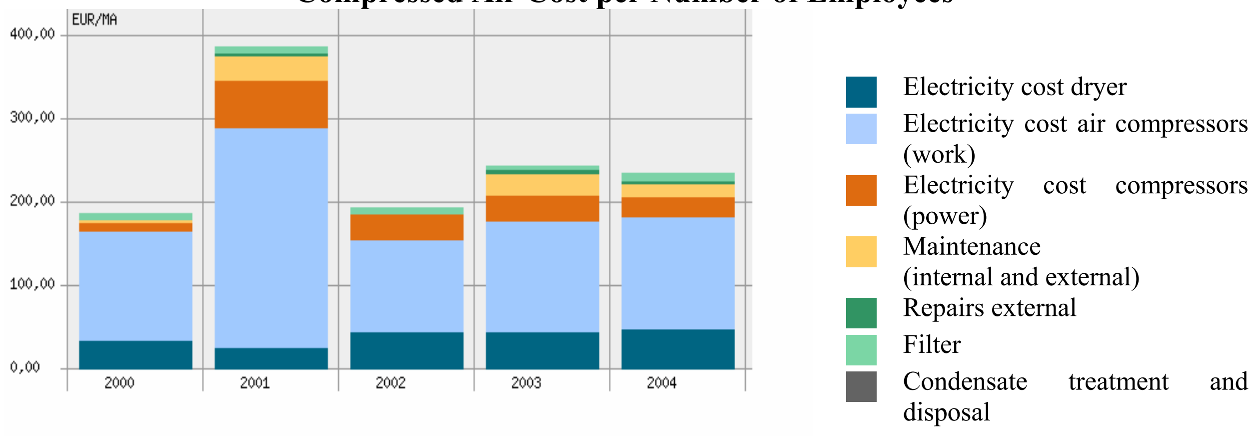


Source: Druckluft effizient 2004

For the company under consideration, the values vary around 0.1 Euro-cent per Euro turnover, which is a very low value. So compressed air will not be as important for this company as for many others. This is also supported by the results of the indicator "share of compressed air electricity consumption in total electricity consumption", which is in the range from 1.8 to 3.6 % for all years. As can be seen, the cost for compressed air as a share of turnover was highest in the year 2001, mainly due to a significantly increased cost of electricity for the compressors. The power costs were especially high during this year.

In the labour-intensive sectors of industry, the relation of compressed air cost to the number of employees is important. In companies where the share of pneumatic tools is high, the consumption of the site typically corresponds well with the number of people working there, see **Figure 3**. It is also an indicator of the extent to which the production is running automatically. Companies which are producing high quantities of products with a small number of employees, such as is the case in the manufacture of glass or cement, will have typically high values. Typical values for the compressed air cost per employee are in the range from 10 to 10 000 Euro.

Figure 3: Results of the Internal Benchmarking: Indicator 2:
Compressed Air Cost per Number of Employees

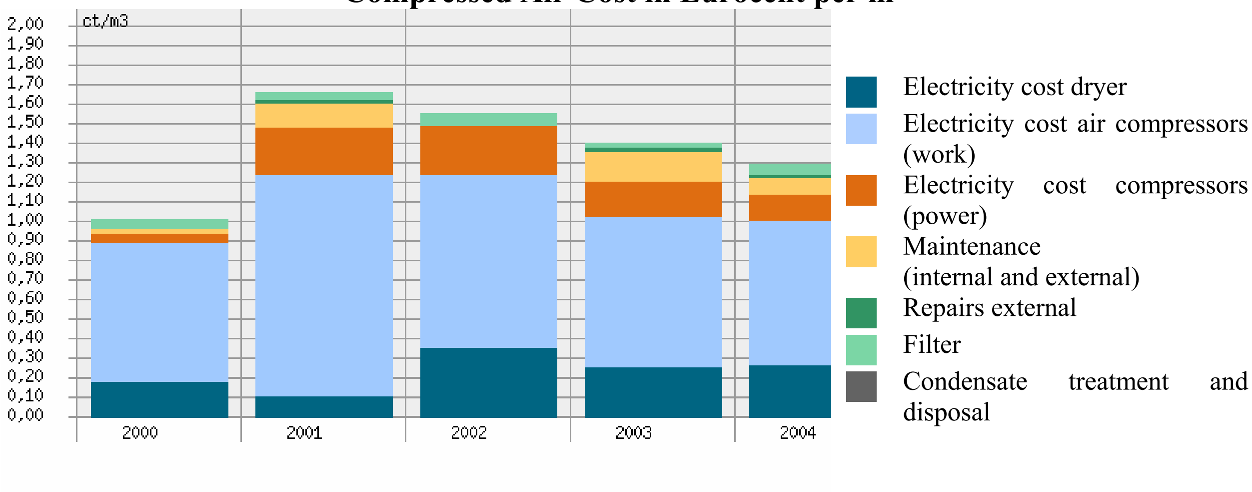


Source: Druckluft effizient 2004

The indicator attracting most attention is typically the "specific cost of compressed air expressed in Eurocent per cubic meter of air". This value, which depends on the pressure level, the required air quality, and other factors, is a key indicator for comparison. However it should be kept in mind that some parts of the cost, such as man hours for maintenance, are often not correctly allocated to the generation of compressed air. Neither does the cost data include the investment cost. The values obtained are typically in the range from 0.5 to 2.5 Euro-cent per cubic meter, see **Figure 4**.

If investment costs are taken into account, this typically adds about 10 to 25 % to costs, depending on the size and the number of operating hours of the compressed air system. About 60 to 80 per cent of the life cycle costs of compressed air systems are typically related to energy consumption. Therefore the limit placed on the operation and maintenance cost in the benchmarking seems to be appropriate. In addition it should be taken into account that investment costs depend heavily on the size and purchasing power of a company. The same compressor can have a price from 50 to 140 % of its list price, depending on the customer. However this improvement potential lies outside the scope of an optimization aiming at identifying the economic energy saving potential. **Table 2** summarises the results of the calculations in absolute values.

Figure 4: Results of the Internal Benchmarking: Indicator 3: Compressed Air Cost in Eurocent per m³



Source: Druckluft effizient 2004

Table 2: Detailed Data for the Composition of the Different Indicators

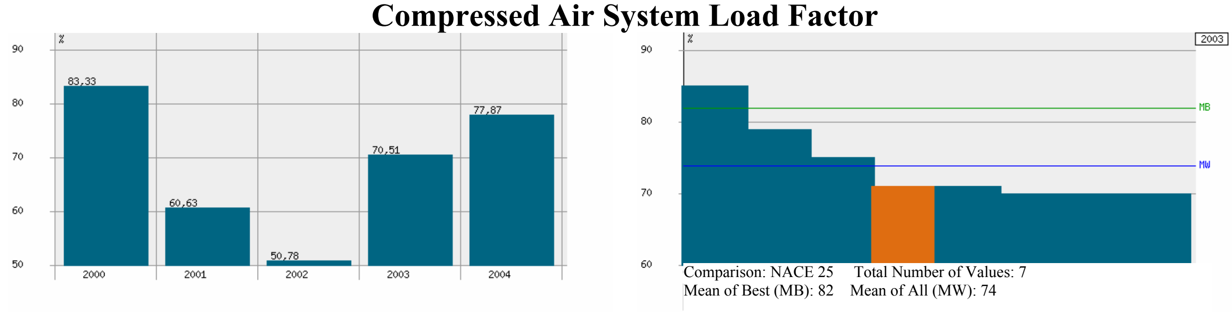
		2000	2001	2002	2003	2004
Electricity cost dryer	[EUR]	4,480.00	2,520.00	4,480.00	4,480.56	4,592.00
Electricity cost air compressors (work)	[EUR]	16,960.00	26,460.00	11,036.00	13,318.00	12,736.00
Electricity cost compressors (power)	[EUR]	1,250.00	5,625.00	3,125.00	3,125.00	2,343.75
Maintenance (internal and external)	[EUR]	525.00	3,000.00	not known	2,625.00	1,500.00
Repairs external	[EUR]	5.00	400.00	not known	500.00	250.00
Filter	[EUR]	1,000.22	700.00	696.00	350.00	870.00
Condensate treatment and disposal	[EUR]	300.00	350.00	500.00	1,500.00	1,200.00
Total cost	[EUR]	24,520.22	39,055.00	19,837.00	25,898.56	23,491.75
Turnover	[Mill. EUR]	20.000	23.123	24.000	25.000	26.000
Total cost/Turnover	[ct/EUR]	0.123	0.169	0.083	0.104	0.090
Number of employees	[MA]	130.00	100.00	100.00	100.00	95.00
Total cost per employee	[EUR/MA]	188.62	390.55	198.37	258.99	247.28
Compressed air production	[Mill. m³]	2.400	2.338	1.248	1.733	1.723
Total cost per m3	[ct/m³]	1.022	1.671	1.590	1.495	1.363

Results of External Benchmarking

The external benchmarking is the second step of the analysis. In the external benchmarking targets for the company's own indicators can be obtained based on the operating practices of competitors. Whenever possible, the comparison is made on the 4-digit NACE code but, for the example given, there were not enough data available on this detailed level. Instead, the group of companies with the same 2-digit NACE code were used for comparison. The automatically generated benchmarking report also contains the maximum, minimum and average values for each indicator for all levels of detail, ranging from the 4-digit NACE code up to all the data sets available.

Figure 6 shows the results for the indicator "compressed air system load factor". It is well known that idling compressors are very common in industry due to fluctuating compressed air demand. However, this idling represents one source of useless electricity consumption. A low load factor indicates that the compressors are not correctly sized for the air requirements of the company. The correct splitting of the compressor system or the use of frequency controlled compressors can significantly reduce this part of electricity consumption. For a better insight, the results of the internal benchmarking for this indicator are shown alongside the values from the external benchmarking. 7 data sets are available at the 2 digit NACE code level. The mean value of the load factor for these companies was calculated to be 74 %. By averaging the best values, a much higher mean value of 82 % is obtained.

Figure 6: Results of the Internal and External Benchmarking: Indicator 9: Compressed Air System Load Factor

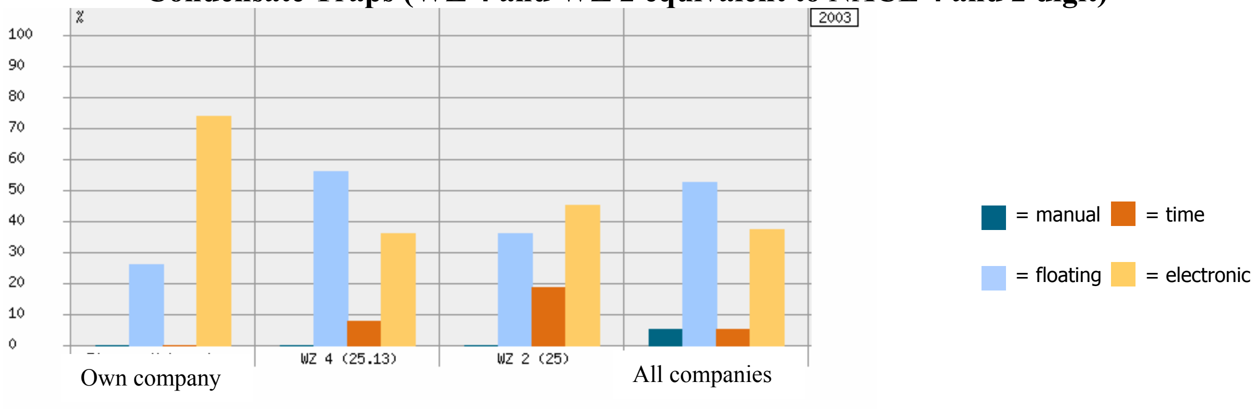


Source: Druckluft effizient 2004

The company under analysis only achieves a load factor of 70.5 % in 2003, the year for which the external benchmarking was conducted. The results of the benchmarking also include some information on how to improve the indicator. The additional information presented depends on the results of the benchmarking. If the company's own value is better than the mean of the best, general information is provided. If the value is between the two averages, possible reasons are suggested and explained and it is recommended to look at the other indicators to keep the user focused on areas where the largest potentials are found. If the value is below average, practical tips are given on what to do to improve the situation. In the case of the load factor, for example, the low load factor may be caused by the under dimensioned size of the storage tank or an inadequate pressure control at the compressors.

In addition to the indicators related to energy consumption and costs, more general indicators are also calculated. **Figure 7** shows the use of different types of condensate traps. The most common condensate traps used in industry are floating traps. The main problem with this type of condensate trap is that the trap may get blocked and cannot close completely. If this is the case, the trap then functions as a continuous leak. Another common type are time-controlled traps, which need to be adjusted to the maximum amount of condensate possible. However, since humidity changes throughout the year, the trap might open even in the absence of any condensate and compressed air is then blown off instead. Therefore electronic traps should be used. Today about 50 % of traps used are of the floating type and 35 % are electronic. However, in some sectors of industry these shares are very different; for example, in NACE 25.13, "Manufacture of other rubber products", 20 % of condensate traps are still time-controlled, which indicates a vast potential for improvement.

Figure 7: Results of the Internal and External Benchmarking: Indicator 23: Condensate Traps (WZ 4 and WZ 2 equivalent to NACE 4 and 2 digit)



Source: Druckluft effizient 2004

Conclusions

A benchmarking system was developed for compressed air systems as part of the German Compressed Air Campaign and has been available online since 2004. Since the launch of the system, about 120 companies from different sectors have participated in the system to benchmark their compressed air systems in order to receive up-to-date information about the performance of their systems compared to best practices. The benchmarking is being promoted still further in order to increase the number of participants so that, ultimately, each user will be able to compare themselves directly with other companies from the same sector. In addition, companies taking part in the benchmarking project can ask for help if they have doubts about the results or are not able to interpret them.

The benchmarking approach has proven to be a very effective instrument for analysing compressed air systems without having to make expensive measurements of the system. Nevertheless, benchmarking will not be able to completely replace on-site measurements and analysis, as it is not able to account for all the specialities of a compressed air system. This is especially true for end uses of compressed air. If, for example, compressed air is used for cooling, it might be able to be replaced by a simple blower with much lower energy consumption. However as the number of possibilities here is too large, these issues are not dealt with as part of the benchmarking and still require an inspection by a compressed air expert.

Acknowledgments

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