African Journal of Business Management Vol. 5(14), pp. 5637-5645, 18 July, 2011
Available online at http://www.academicjournals.org/AJBM
DOI: 10.5897/AJBM10.1340
ISSN 1993-8233 ©2011 Academic Journals

Full Length Research Paper

Potential energy savings in compressed air systems in Serbia

Dragan Šešlija[1]*, Ivana Ignjatović[1], Slobodan Dudić[1] and Bojan Lagod[2]

[1]Department of Industrial Engineering and Management, Faculty of Technical Sciences, University of Novi Sad, Novi Sad, Serbia.
[2]Energotehna doo, Novi Sad, Serbia.

Accepted 17 March, 2011

Compressed air systems (CASs), as one of the most important energy carriers in the industry, are targeted as a field full of possibilities for energy savings. Average electricity consumption of the CASs in Serbia is estimated to be 8% of the overall electricity consumption in the industry. This data was obtained based on the share of the amount of electricity consumed in the production of compressed air in the overall energy electrical energy consumption in the polled companies. Although this percentage is low compared to the values reported for some other countries, this does not mean that the CASs in Serbia are more efficient. This low percentage is a consequence of the low price and high energy intensity of electricity in Serbia, so that the portion of wasted energy is much higher than the average in developed countries. The present paper describes the state of CASs in Serbia and relates it to that in some other countries, highlighting some of the most frequent and most significant issues. Besides, the recommendations are given on potential savings, which are estimated to amount to at least € 8.07 million per year. To achieve this, it would be necessary to raise the awareness of the employees of the importance of saving energy and implement a national program of energy efficiency in CASs.

Key words: Compressed air system optimization; energy efficiency; energy consumption.

INTRODUCTION

According to the Kyoto Protocol from 1997, the EU has to reduce greenhouse gas emission by 8% below the level from 1990 by the 2008-2012 periods. To achieve these reductions, substantial efforts have to be undertaken in all branches of human enterprise. Serbia, as a European country, has to contribute to the overall efforts to decrease greenhouse gas emission, and therefore, the Serbian Government has to work out and implement an appropriate energy policy. One of the important industry utilities that have to be encompassed by this energy policy is compressed air systems (CASs).

The application of compressed air has had a growing trend due to its easy and safe generation, manipulation, and usage. In previous years, the research efforts in this domain were concentrated on the CASs development and application aimed at boosting the productivity regardless of the energy consumption. With increased awareness of the energy costs as well as the effects of greenhouse gas emission, the attention has been recently placed on the energy efficient use of compressed air.

The experience gained in numerous CAS optimization projects, as well as the opinions of the experts in the field, indicated that many industrial systems are missing the chance to improve energy savings with the relatively low costs of projects for increasing energy efficiency (Yuan et al., 2006).

Energy saving measures in CASs that have been identified in the course of energy audits in the industrial small and medium enterprises may yield an average energy saving of nearly 15%, with a payback of two years, the energy saving potential in some of them amounting from 30% up to even 60% (USDOE, 2001). The basis for all decisions concerning energy efficiency of the existing CASs is the understanding of the way of their functioning and existence of appropriate data. In that sense, it would be necessary to make measurements of consumed electricity of compressors, airflow, system leakage and pressure drop in the system.

*Corresponding author. E-mail: seslija@uns.ac.rs. Tel: +381 21 4852167. Fax: +381 21 459536.

A number of common technical measures can improve energy efficiency of CASs, some of the most important being (Al-Mansour et al., 2003):

1. Reduction in waste air due to inadequate maintenance and leaks,
2. Improving control systems,
3. Reduction of pressure drops,
4. Better maintenance and operation,
5. Building of an air valve sub-system for separation.

Besides energy savings, increasing energy efficiency of CASs may ensure other significant benefits for the enterprise. Energy saving measures implies a high monitoring level of CASs and appropriate maintenance. That leads to decreased breakdowns of production equipment, avoiding of the loss of raw materials or other inputs, longer life cycle of pneumatic devices and higher reliability of CASs. Often, these benefits are more valuable than the energy savings.

This paper is concerned with the identification of the current state of energy efficiency in the production and usage of compressed air in the industry of Serbia and possibilities for improvements that would yield the corresponding energy saving. In order to compare the findings with those for some other countries, first a brief outline of the state of CASs in the USA, European Union, China, and Vietnam were given. The USA was taken because of its leading position in the industry; European Union because Serbia is part of Europe; China as an example of the fast-growing industry, and Vietnam as a typical example of a developing country.

ENERGY EFFICIENCY OF CASS

USA

A key finding of a survey carried out within the "Motor Challenge Program" (MCP), launched in 1993, was that 20% of all US electricity was used to operate industrial motor-driven systems, a large portion of this being associated with pumps, fans and blowers, and air compressor systems.

The reported potential savings were over 1 TWh of electricity or USD 3 billion per year, with the existing and new technology by 2010 (or 10% of the total energy cost of industrial motor-driven systems). System improvement opportunities were recognized in motor sizing and proper matching to load, improvements in the system layout, updating and well-maintaining controls, improving operation and maintenance, and use of adjustable speed drives (McKane et al., 1997).

The MCP was followed by the project "Compressed Air Challenge" of the US Department of Energy (USDOE, 2001). One of the most significant findings of this project was that the CASs energy consumption in a typical manufacturing facility could be reduced by 17% through appropriate measures, with a payback of 3 years or less. Apart from these energy savings, improvements to the energy efficiency of CASs could also yield some other important benefits to the end users, such as reliable production, less rejects, higher quality, etc.

European Union

The European Commission launched the "Motor Challenge Program" with the aim to overcome energy efficiency barriers. Of the total electricity consumption in the EU-15 in 2000, of the overall 2,574 billion kWh, 951 billion kWh were used in the industry. Of this, 614 billion kWh, or 65%, was consumed by motor-driven systems. It was estimated that the potential saving could be 181 billion kWh, (29%), or seven percent of the overall electricity consumption (De Keulenaer et al., 2004).

According to the study "Compressed Air Systems in European Union" (Radgen and Blaustein, 2001), the EU-15 was spending 10% of the total electricity consumed in the industry for the production of compressed air. The most important potential energy savings are related to the system installation and renewal (the overall system design, improvement of drives, use of sophisticated control systems, recovering heat waste, improved cooling, drying and filtering, reducing frictional pressure losses, etc.) and system operation and maintenance (reducing air leaks, more frequent filter replacement, etc.). The percentages of potential saving varied from country to country. For instance, Germany spent seven percent, United Kingdom 10%, Italy, France and the rest of EU 11% (Radgen and Blaustein, 2001). Details on potential energy savings can be found in the corresponding references: for Germany in (Radgen, 2004) and (Radgen, 2003), for Switzerland in (Gloor, 2000), for Sweden in (Henning, 2005), and for Austria in (Kulterer and Weberstorfer, 2007).

China

The electricity consumption of CASs in Chinese enterprises goes from 10% up to 40% (Li et al., 2008) of the total industrial electricity consumed. According to (Li et al., 2008), the most widely used compressors in China are reciprocating compressors, often several decades old.

To meet increased compressed air demands, many enterprises have undertaken retrofits of their CASs, yielding increased compressor capacity, improved system piping, etc.

The most frequently implemented energy saving measures are: purchasing rotary screw compressors, application of variable speed drives and changes to the piping system to allow centralized production of compressed air, etc.

Vietnam

A key element of the "National program on energy conservation and efficiency in the period of 2006–2015" is the energy efficiency audit. As an example, the audit of a footwear factory (Ming, 2009) showed that the CAS operation was not optimized. Many air compressors were working for artificial demands. Another important issue was the air leakage, wasting over 65% of the compressed air. Because of all this, the overall energy efficiency of the CAS was less than five percent. To overcome this it was suggested to invest about USD 84,000 in the first year and USD 41,400 in each of the forthcoming years, which would help the factory to save USD 195,700 each year.

METHODOLOGY

The Serbian Ministry of Science and Technological Development initiated the "National Program of Energy Efficiency", with many subprojects, one of them being "Increasing Energy Efficiency of Compressed Air Systems in the Industry", within which this study was carried out.

In order to acquire information about the current energy efficiency of CASs in Serbian industry a survey was carried out during 2006. The objective was to help the systems' operators to analyze and optimize the actual state of their CASs, define priorities for energy saving and demonstrate the company's saving potential, not only in a qualitative but also in a quantitative way. The study encompassed companies from all branches of the industry, with the emphasis on the air pressure up to 10 bars. The choice of the companies was made following the selection pattern of the USA (USDOE, 2001) and German (Radgen, 2003) studies. According to the Serbian Business Registers Agency, the number of production enterprises in Serbia in 2009 was 40,000 (SBRA, 2009), the number of those with a CAS being unknown. The survey included 52 such companies, four from each industry group. Exceptions were the food and beverage industries, represented by ten and nine enterprises, which is in proportion to the number of companies from these branches and their participation in the Serbian market. For instrument industry group, we chose only two companies, because this field is rather undeveloped. Of course, the data would be more reliable if more companies were included, but this study should not be seen as the final and full description of CASs and possibilities of their improvements, but rather as a pilot project dealing with the current state of CASs in Serbia.

The data were collected through a questionnaire specially designed for this study. The questionnaire was provided to the companies by post, e-mail, or in direct contact. The questionnaire had the following parts:

1. General information about company
2. General information about the CAS
3. Applied CAS control methods
4. Maintenance of CAS
5. CAS audit.

Special attention was paid to:

1. User’s specifications
2. Specifications of the CAS
3. actions carried out in CAS control and maintenance
4. ACTIONS for increasing energy efficiency of the CAS
5. Problems and limitations that occurred in the implementation of these actions.

As a preparation for this study, walkthrough audits in a dozen of Serbian companies have been done, while paying special attention to the compressor rooms, distribution systems, end-uses of compressed air and leakage rate.

RESULTS AND DISCUSSION

Compressors

The majority of the companies polled in the survey (72%) have compressors with motor power up to 500 kW (Table 1), and these data approximately match those for highly developed countries (USDOE, 2001). Nearly half of the companies have medium-size compressors, which can be easily adjusted to different demands, for example, with the introduction of variable frequency drives. It can be noticed that the largest percentage of consumption of electricity for compressed air generation in comparison with the overall electricity consumption is in the primary metal industry and fabricated metal industry. Electricity consumption for compressed air production is significantly below the average only in the textile industry.

The column "unknown" indicates a relatively bad situation in some of the companies. The people from maintenance department and other technical services do not know even the power rating of their compressors because they are old, technical documentation is not available and technical specifications of motors are lost.

In contrast to the situation in Europe, where screw compressors are the most common (Radgen and Blaustein, 2001), the compressors in the CASs of the Serbian industry are mainly reciprocating compressors. Namely, assuming that the polling sample is representative enough, it can be said that these compressors make more than 60% (single-acting 40.3% and double-acting 20.8%), whereas rotary screw compressors make 37.6% of the total number of compressors.

One of the ways of increasing energy efficiency of the CASs is to replace reciprocating single-acting compressors with rotary screw compressors. Although the former compressors are efficient in the applications up to 25 kW, in the polled companies they are used in the applications that require even seven times higher power. If the old reciprocating single-acting compressors in the polled companies were replaced with rotary screw compressors, which are by 20% more efficient (Prator, 1998; Norgren, 1999; Ambrosino, 2008), it would be possible to save about 3.23 GWh/year (Table 2). If this data is related to the overall industrial electricity consumption in Serbia it comes out that the potential saving in CASs could be 2.8% or 15.20 GWh (in 2008).

Considerable attention should be paid to the

Table 1. Installed motor power and number of compressors in the polled companies.

Industry group	Installed motor power in CASs (kWh)	Participation of CASs in total electric consumption (%)	Installed motor power of air compressors (kW)				
			<100	100-499	500-999	>1,000	unknown
Primary metal industry	7,890	50		1		2	
Beverage industry	4,490	-		2	3	2	
Rubber and plastic products	3,204	-	1		1	1	
Chemical industry	1,995	-	1	2		1	1
Food industry	1,546	-		7			
Machine and equipment industry	1,230	-		2	1		
Stone, clay and glass products	955	5-15		2	1		
Petroleum and coal products	644	5-20	2		1		
Fabricated metal products	479	20-50	1	2			
Instruments	420	10-30		2			
Paper and allied products	287	-	1	1			
Textile industry	182	2-10	1	1			
Press and publishing	171	-	1	1			
Furniture	120	-	2				
Electronic and other electric equipment	83	5-40	2				2
Leather and leather products	-	-	1				2
Number of compressors (%)			24	43	13	11	9
Total	23,696						

procedures of compressor control and maintenance, especially because 53% of users have four or more compressors in their compressor rooms. However, the findings do not comply with this requirement. This study indicated that the users' awareness of the benefits of latest compressor control systems is on a concernedly low level. (Table 3) gives compressor control methods that are in use in Serbia. As can be seen, start/stop is the most common control method, although it does not allow to maintain a stable system flow and pressure in an energy efficient way. The more efficient method, frequency regulation, is used in only 20.4% companies. However, in about 18% of polled companies the introduction of this sophisticated method of compressor control is not economically justified, because they are of relatively low power (2 - 7.5 kW). In the rest 61.2% companies, which use 92.4% electricity in the polled sample, the start/stop regulation could be replaced by frequency regulation, and thus save 10% (Wissink, 2007) of the total electricity consumed in the CASs, that is 54.9 GWh (for 2008) (Table 4).

In order to use and control compressors in a best way it is very important to understand the facility's unique air usage profile, which includes the percentage of the time that the motor will be operating in various load conditions, and also how the motor has been matched to the

Table 2. Potential savings in the polled companies achievable by replacing reciprocating single-acting compressors with rotary screw compressors.

Industry segment	Installed motor power (kW)	Electricity consumption (kWh/year)	Motor power where replacement can be done (kW)	Electricity consumption where saving can be made (kWh/year)	20% savings (kWh/year)
Food Industry	1,546	10,887,136	270	1,617,408	323,482
Beverage Industry	4,491	59,014,904	1,326	7,971,704	1,594,341
Fabricated metal products	509	1,998,880	165	343,200	68,640
Machine and equipment industry	1,270	5,861,960	260	3,569,280	713,856
Instruments	420	760,500	420	760,500	152,100
Electronic and other electric equipment	83	172,640	72	149,760	29,952
Rubber and plastic	3,204	30,698,304	74	646,464	129,293
Stone, clay and glass products	963	7,317,440	148	1,077,440	215,488
Total		116,711,764		16,135,756	3,227,151

Table 3. Compressor control methods.

Control method	Company (%)
Start/Stop	71
Frequency regulation	20
Inlet modulation	16
Dual control	4
Variable displacement	2

compressor power requirement (Talbott, 1992). By applying new control methods and adjusting them to the demand changes by shift or time of the day, significant energy savings could be achieved. In simple words, there is a high potential for upgrading compressors' functioning in the polled companies.

Distribution system

In the majority of polled companies, the oldest segment of the CAS is the distribution (piping) system. Distribution systems are one of the least understood, but at the same time, an essential element of CASs. Usually, and this is especially true for old factories, the piping systems are places where so much energy is lost and so much maintenance is incurred.

The distribution system can be inappropriate for the new demands in production and should be adjusted by diameter and kind of material to new expansions in the production. The survey showed that steel pipes are installed in 82% of Serbian CASs. New materials for piping systems, like plastic and copper, are in use in only ten and three percent, respectively, of companies. It can be concluded that the distribution systems are, in average, aged and often neglected. In addition, this indicates that the employees and management are not sufficiently informed about the advantages of new materials for pipes, or they do not have finances to invest in retrofitting of the distribution system. However, the data collected did not allow us to make a quantitative assessment of the potential savings.

Maintenance

In the assessment procedure, the users were asked to list regular maintenance activities that they performed, and the results are presented in (Table 5).

As can be judged from their answers, all companies perform certain maintenance activities. These data can mislead us to believe that the companies pay due attention to their CASs. However, if these data are related to the fact that 67% of polled users said that they carry out maintenance activities just in case of malfunctions, it can be easily concluded that there is no detailed, or even any, plan for preventive maintenance. Similar practice has also been observed in some other countries (USDOE, 2001).

Table 4. Potential savings achievable by introducing frequency regulation of compressors.

Compressor control method	Companies (%)	Installed motor power (kW)	Electricity consumption per year (kWh)	Electricity consumption per year (%)	Savings/year (%)	Savings/year (kWh)
Frequency regulation	20.4	3,162	13,288,288	7.6		
Frequency regulation not applicable	18.4	567	2,301,000			
Frequency regulation applicable	61.2	20,333	189,307,716	92.4	10	18,930,772
Total						18,930,772

Table 5. Regularly performed maintenance activities.

Maintenance activity	Company (%)
Check cooling water quality, replace cooling system	47
Check belts for wear and replace	53
Clean air line filters	65
Verify operating temperature per manufacturer specification	71
Check pressure regulators	71
Check lubricant level and filter	78
Clean condensate drains	86
Check for system leaks and their fixing	88
Clean or replace inlet air filter cartridges	94
Other	10

CAS management

One of the questions in the poll dealt with the users' objectives in managing of CASs. The answers mentioned continuous system operation, adequate supply of air and providing proper quality of compressed air as the most important tasks for the reliable functioning of these systems. Contrary to the stated objectives, the real situation was quite different. More than 20% of the companies said that they had problems with their CASs in the past twelve months, the presence of moisture or oil being mentioned most frequently. Namely, the percentages of the companies that stated the presence of water (82%), oil or oil mist (35%) in compressed air are extremely high, exceeding the acceptable level. In comparison with data from the USA study (USDOE, 2001), almost three times more companies in Serbia have had that problem. An explanation for high water and oil content in Serbian CASs may be the fact that a majority of compressors are of reciprocating type, without dryers. The situation in Western European countries is opposite, the refrigeration dryers are standard, and the moisture problem is managed by proper sizing of the dryers and correct operation. Hence, additional efforts should be made to procure appropriate dryers and filters.

As far as the responsibility for CAS management is concerned, in 33% of companies the managers of maintenance departments are responsible for managing CAS; in 18% the responsibility is on field engineers, and in the rest of companies this is the duty of some other employees. However, the responsibility for managing CAS is usually shared among the managers of several departments: production manager, maintenance manager, financial manager, etc. This is the reason why it is so complicated to make and apply in practice any decision concerning the priorities in managing of CASs. Smaller plants are less likely to be able to afford a full- or part-time energy or productivity manager on site, or conduct a comprehensive energy and productivity audit to identify and implement saving opportunities (Alhourani and Saxena, 2009).

Investments

More than 67% of companies have the CASs that are 10 or more years old (either compressor or distribution system), which is a very disturbing fact. In 87% of factories, the equipment is older than five years, which indicates the lack of investment in CASs due to the overall bad situation in the economy of Serbia.

More than one half (51%) of the polled users have had some investments in certain parts of their CASs aimed at improving the energy efficiency; a great majority of those that invested (88%) bought new compressors. After that come the procurements of filters and dryers, with 64% and 52% respectively. More than one third retrofitted their distribution systems because they were dilapidated and leakages were very high. Only 20% of the users invested in compressor control systems. As the main reasons for the absence of capital investments, the polled companies mentioned the lack of financial resources (48%), unawareness of the importance of CASs for proper manufacturing, or lack of understanding of the benefits that the investment would bring to the factory.

A serious problem represents the fact that 49% of the companies did not have any investment in their CASs since they started to work. In some cases, it is more than thirty or forty years. Still, the majority of the polled users invested in their compressor facilities, but those investments were more than eight years ago. Big investments, such as retrofitting of the entire system, are rather rare (only 24%). Other investments are mostly individual and targeted on filters, dryers, and pressure regulators.

Methods applied to increase the energy efficiency of CASs

One of the questions was related to the studies of energy efficiency. Only one of the 52 companies undertook the energy efficiency study of its CAS.

It encompassed the evaluation of exploitation of compressed air, identification of unnecessary and inappropriate usage of compressed air, measuring of pressure drop, and recommendations for enhancement of the CAS efficiency.

The main reason for not implementing measures for increasing energy efficiency was the lack of money, 33% stated this as the main problem; 27% of users mentioned that they have other problems and priorities concerning production, and therefore, they did not have time to pay attention to CAS. Nearly one third considered that they did not need to apply measures for increasing energy efficiency. Other barriers mentioned were the lack of communication and shared responsibility between the maintenance department (which is typically responsible for the system operation) and plant engineers (who are focused on meeting the needs of production departments). In 13% of cases, the management staff were not interested in increasing efficiency of CASs. Very common problems are the lack of knowledge and skilled employees as well as the lack of measuring devices.

The number of procedures applied to increase energy efficiency is quite small. There is no correlation between installed power of compressors in the plant and the number of activities implemented to increase the energy efficiency. Large systems are naturally large of energy, and there are a lot of possibilities and situations where compressed air can be saved or used in a more appropriate manner. On the other hand, large systems are usually carefully planned and installed, and, if the design is good, many options for energy efficiency have already been implemented in the system.

Identification and repair of leaks in the air distribution system and at the end-use tools can reduce the system's energy consumption. This alone can make 42% of the overall savings potential (Radgen and Blaustein, 2001). Prevention of air leaks is an essential measure of energy saving. For example, it was reported that in the New Zealand companies the 50-70% of savings were related to demand side (Neale and Kamp, 2009).

Considering air leaks, the prevention activities have been conducted in the 63% of companies polled; 97% of them consistently checked for the leak near compressors and dryers; 90% always checked valves, shut-off valves, drains, etc; 81% checked joints for leaks; by-pass valves checked 65%, and 55% checked for leakage at regulators and tools. These are surprisingly high percentages for leak detection. This only can confirm that there are huge problems with leakages in Serbian CASs. Our estimation is that leakage rate varies between 20% and 40% of the total air usage. People, who are working there, are aware of the fact that air leakages cause them troubles in the functioning of the system. Hence, in many cases they try to provide faultless functioning of their CASs.

In a majority of companies, the in house employees are in charge of leak prevention activities; certified persons are engaged to do leak prevention program only in 35% of companies.

Potential savings

Based on data of the Electric Power Industry of Serbia (EPS, 2009a), the amount of electricity consumed in Serbia in 2009 was 27,639 GWh. Figure 1a, shows that nearly 7,000 GWh (26%) were used in the industry (Neale and Kamp, 2009), the breakdown by sectors being presented in Figure 1b (RZS, 2009). It is evident that the largest proportions are related to the metal industry, chemical industry, food and beverage industry, etc., in which compressed air is strongly important for proper functioning. Industrial CASs installed in Serbia consume about 8% of the electricity used by industry (Table 6). This data was obtained based on the share of the electricity consumed in the production of compressed air in the overall energy electrical energy consumption in the polled companies. Although this percentage is low compared to the values reported for some other countries (Radgen and Blaustein, 2001; Radgen, 2004; Radgen, 2003), this does not mean that the CASs in Serbia are more efficient. This low consumption percentage is a consequence of the inefficient electricity utilization in the industry, the value of energy intensity being three times higher than in the developed European countries (USEIA, 2006). Besides, the price of electricity in Serbia is relatively low, so that no appropriate attention is given to its

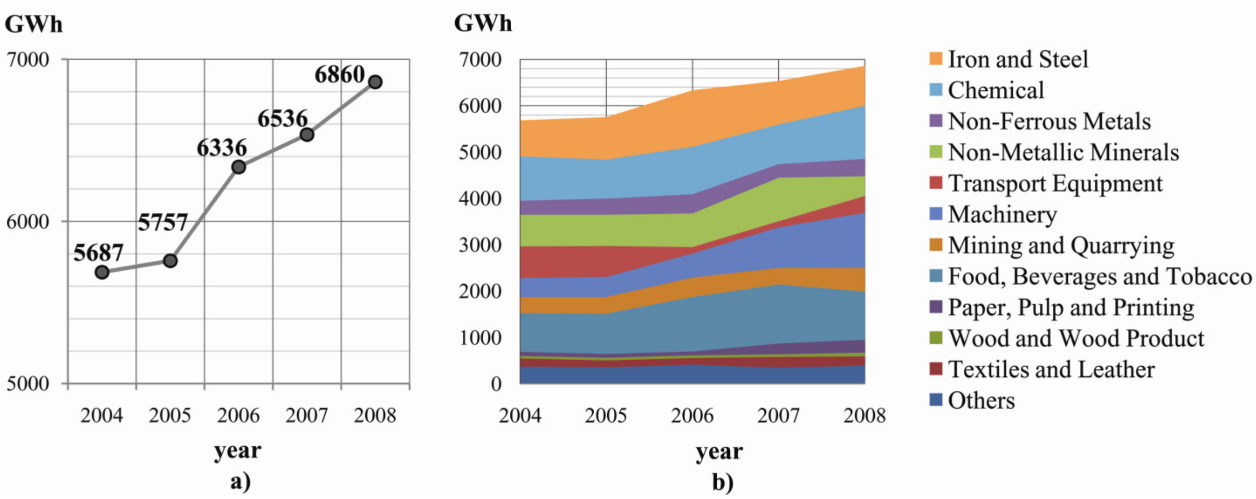

Figure 1. Industrial electricity consumption in Serbia: a) overall industry, b) breakdown by the sectors.

Table 6. Calculated savings.

Variable	**Value**	
Year	2006	2008
Electricity consumption in the industry (GWh)	6,336	6,860
Electricity consumption for compressed air production (GWh)	506.8	548.8
Electricity consumption in CASs of the overall industry consumption (%)	8	8
Electricity consumption in the polled companies (GWh)	116.7	
Energy saving measure	**Savings in CASs (%)**	
Replacement of reciprocating single-acting with rotary screw compressors	2.8	
Frequency regulation instead of start/stop regulation	10	
Reducing air leaks	24	
	36.8	
Total		
Savings (GWh)		201.8
Savings (€)		8,070,666

economic utilization. There is a high potential for increasing energy efficiency of CASs in Serbia. In the sequel, the study will mention some procedures by which substantial savings could be made. All savings are calculated for the year 2006 (when the research was carried out) and extrapolated to the year 2008 (the last year for which we have pertinent statistical data) in accordance with the trend of energy consumption in the industry (Figure 1a and b) (MEM, 2008; RZS, 2009).

As already mentioned (Table 2), one of possible ways of increasing the energy efficiency of CASs is the replace- ment of the reciprocating single-acting compressors with rotary screw compressors, which would reduce the CAS energy consumption by about 2.8%. On the other hand, the introduction of frequency regulation would result in the saving of 10% (Wissink, 2007) (Table 4). If this is combined with the potential saving that could be achieved by eliminating air leak in CASs, which is in average 30%, and if this mode of saving is applicable in about 80% of companies (Radgen and Blaustein, 2001), the additional reduction would be 24%. This would result in the potential saving of 36.8% of the total energy consumed by CASs. With the current price, which is regulated by the government, of approximately 0.04 €/kWh (EPS, 2009b), Serbia could save at least € 8.07 million every year (Table 6).

By taking into account the other possibilities of optimization of CAS operation, such as recovering waste heat, improved cooling, drying and filtering, reducing frictional pressure losses, optimization of end-use losses, etc., it can be estimated that the above saving of 36.8% might well exceed 40% of the total electricity consumed by the CASs in Serbia.

CONCLUSIONS AND RECOMMENDATIONS

A general conclusion that can be drawn from studying the current state of CASs in Serbia is that there is a lot ofroom for improvement in these systems. The potential measures that could be undertaken may be related to the technical aspects of their proper functioning and readiness of the company's policy-makers to pay due attention to this issue, which is in some cases of the essential importance for the function of the company as a whole. However, a prerequisite for this is to raise the awareness of all the people involved of the importance of energy utilization optimization and of all the benefits that can be thus achieved. In that sense, it would be desirable to publish the appropriate guides and organize seminars dealing with energy efficiency of CASs, as well as to develop the best practice programs.

The first step in Serbia was already made by publishing the "Guide for increasing energy efficiency of compressed air systems" (Šešlija, 2008).

Based on the findings of this study we can recommend some general measures to be undertaken with the aim to improve the energy efficiency in CASs in the industry of Serbia:

1. Reducing air leaks
2. Replacement of old compressor unit with new, more energy efficient ones
3. Replacement of old, devastated distribution systems with the appropriately designed new distribution system,
4. Improvement of compressor control systems by introducing frequency regulated drives and multiple compressor control systems
5. Recovering of waste heat.

In addition, it is highly recommended to introduce a position of energy manager, who will be responsible for both producing and using compressed air.

This study demonstrated how some technical and non-technical measures could improve energy efficiency in the Serbian industry, particularly in the CASs, and brings about remarkable savings. Hence, they should be a high national priority.

ACKNOWLEDGEMENTS

This study was supported by the Ministry of Science and Technological Development of the Republic of Serbia (Project EE-232016). The authors also wish to thank all the companies that participate in the survey.

REFERENCES

Alhourani F, Saxena U (2009). Factors affecting the implementation rates of energy and productivity recommendations in small and medium sized companies. J. Manuf. Syst., 28(1): 41-45

Al-Mansour F, Merse S, Tomsic M (2003). Comparison of energy efficiency strategies in the industrial sector of Slovenia. Energy. 28(5): 421-440

Ambrosino N (2008). Dare to compare air compressors. Plant Serv., pp. 34-38

De Keulenaer H, Belmans R, Blaustein E, Chapman D, De Almeida A, De Wachter B, Radgen P (2004). Energy efficient motor driven systems. European Copper Institute

EPS-Electric Power Industry of Serbia (2009a). Technical annual report. Belgrade

EPS-Electric Power Industry of Serbia (2009b). Prices. Belgrade.

Gloor R (2000). Energy savings in compressed air systems in Switzerland. Electricity Research Program (project number 33 564), Swiss Federal Office of Energy

Henning D (2005). Electricity - what and how much in Swedish industry. A project of Energy authority's research program, Swedish energy agency.

Kulterer K, Weberstorfer C (2007). Motor Challenge Programme in Austria–Improving industrial energy efficiency, In: Proceedings of ECEEE 2007. Summer study. Saving energy – just do it!; La Colle sur Loup, France

Li L, Yuqi L, McKane A, Taranto T (2008). Energy efficiency improvements in Chinese compressed air systems. Lawrence Berkeley National Library, University of California eScholarship Repository 2008; Paper LBNL-63415

McKane A, Scheihing P, Cockrill C, Tutterow V (1997). US Department of Energy's Motor Challenge: Developed with Industry for Industry. Lawrence Berkeley National Library, University of California, Industrial energy analysis, Paper LBNL-43887

MEM-Ministry of Mining and Energy, Republic of Serbia (2009). Energy balance of Serbia 2008, 2009. Belgrade

Ming Y (2009). Air compressor efficiency in a Vietnamese enterprise. Energy Policy, 37(6): 2327-2337

Neale JR, Kamp PJJ (2009). Compressed air system best practice programmes: What needs to change to secure long-term energy savings for New Zealand?, Energy Policy., 37(9): 3400-3408

Norgren Ltd (1999). Energy Saving. The Norgren guide to saving energy in compressed air systems

Prator D (1998). Variable speed drives cut compressor energy costs, Plant Eng., 52(11): 52-54

Radgen P, Blaustein E (2001). Compressed air systems in the European Union, energy, emissions, saving potentials and policy actions. Stuttgart, Germany: LOG-X Verlag GmbH

Radgen P (2003). The "Efficient Compressed Air" Campaign in Germany - Market transformation to activate cost reductions and emissions savings. ACEEE Summer Study on Energy Efficiency in Industry; 2003; Rye Brook, New York

Radgen P (2004). Compressed air system audits and benchmarking. Results from the German compressed air campaign "Druckluft effizient". In: Proceedings of ECEMEI, Third European Congress on the Economics and Management of Energy in Industry; 2004; Rio Tinto, Portugal.

SBRA-Serbian Business Registers Agency (2009). Companies register. Belgrade

RZS-Statistical office of the Republic of Serbia (2009). Industry and Energy Sector Statistics. Belgrade

Šešlija D (2008). Guide for increasing energy efficiency of compressed air systems. Belgrade, Serbia: SIEEN-Serbian Industrial Energy Efficiency Network

Talbott E (1992). Compressed Air Systems: A guidebook on energy and cost savings. 2nd ed. Lilburn (GA): The Fairmont Press, Inc

USEIA-US Energy Information Administration (2006). Independent Statistics and Analysis. International Energy Annual 2006. International and United States Total Primary Energy Consumption, Energy Intensity, Washington DC

USDOE-US Department of Energy (2001). Assessment of the market for compressed air efficiency services. DOE/GO-102001-1197; Washington DC

Wissink E (2007). Possibilities for saving energy in part load's-Hertogenbosch, The Netherlands: GEA Grasso B.V.