ENERGY AUDITING AND ENERGY SAVING MEASURES IN "ZASTAVA AUTOMOBILI" FACTORY

by

Dušan R. GORDIĆ, Milun J. BABIĆ, Dubravka N. JELIĆ, Davor N. KONČALOVIĆ, Nebojša M. JOVIČIĆ, and Vanja M. ŠUŠTERŠIČ

Original scientific paper
UDC: 629.331:620.92
BIBLID: 0354-9836, *13* (2009), 1, 185-193
DOI: 10.2298/TSCI0901185G

This paper deals with energy audit procedure implemented on only Serbian car manufacturer "Zastava Automobili". Based on the results of energy auditing and performed technological and economical feasibility studies several energy saving measures were proposed. The measures are related to different energy sources: steam, hot water, compressed air, electricity, and water. Such energy efficiency programs reduce energy costs and increase production profitability of the factory.

Key words: *energy auditing, energy saving measures, car industry*

Introduction

Today the main focus of automobile manufacturers is on the technical maintenance of production, and in long-term corporate planning on the search of new markets. Energy saving at best becomes an issue when it is necessary to modify the production plant or to perform replacement investments, or when supply or bottle-neck arise. But as soon as the immediate problems are solved, energy saving is put aside again [1].

Nevertheless uncertain energy prices in today's marketplace negatively affect predictable earnings. Successful, cost-effective investment into energy efficiency meets the challenge of maintaining the output of high quality product with reduced production costs. Beside, energy-efficient technologies often include "additional" benefits, increasing the productivity of a company further. Finally, energy efficiency is an important component of a company's environmental strategy. In short, energy efficiency investment is sound business strategy in today's vehicle manufacturing environment. Therefore, management of the factory together with the research team from the Faculty of Mechanical Engineering, Kragujevac, Serbia, initiated a project to increase the energy efficiency in the factory and to reduce total costs of car production. Based on performed energy auditing and balancing, costly effective identified measures/projects for energy savings in the factory should be implemented. Some of them with the shortest payback time were implemented during the project realisation.

Energy auditing

An energy audit (also called energy survey, energy analysis, and energy evaluation) in an industrial enterprise has an important role in identifying energy saving possibilities of the en-

terprise. It is a procedure that analyses the way energy is currently used and identifies alternatives for reducing energy costs. The aims of the industrial energy audit are:
- to identify the types and costs of energy use,
- to understand how that energy is being used – and possibly wasted,
- to identify and analyse alternatives that can substantially reduce energy costs,
- to perform an economic analysis on those alternatives and determine which ones are cost effective for the industry, and
- to establish a plan to implement energy saving projects [2-5].

The outcome of the industrial energy audit provides information about the present energy use of the enterprise. The energy audit should be conducted accurately enough to identify and quantify the energy savings that are likely to be realised.

In order to conduct the energy audit in "Zastava Automobili" factory, several visits were made for assessment of plants, procedures and relevant documentation that describe the technology and energy system in order to propose energy saving measures. Internal expert team was formed and relevant employees were interviewed concerning the energy consumption. Beside, some measurements were made using portable measuring equipment: portable flow meter, ultrasonic thickness gauge, 3-phase power analyser, infrared camera, infrared thermometer, anemometer, laser photo/contact tachometer, and flux-meter.

Systematized data of energy consumption in "Zastava Automobili" factory are shown in tab. 1 and figs. 1 and 2. The energy audit showed that energy costs in the factory are relatively big and that they exceed 3.4 millions of € annualy. Approximately 43% of all used energy sources goes on heat fluids (steam and hot water) which presents about 45% of total energy costs (fig. 2). It should be noted that water costs are rather high, about 11% of overall costs (about 400.000 per year). Despite the fact that electricity consumption is about 26%, due to relatively low electricity price, electricity costs are only 19% of overall energy costs.

Table 1. Average annual energy consumption

Average annual consumption for 2004 and 2005						
Energy source	Consumption	Unit	Equivalent energy		Annual cost	
			MWh	%	€	%
Steam	9.604.00	MWh	9.604.00	13.64	490.561.32	14.39
Hot water	20.684.50	MWh	20.684.50	29.38	1.055.520.98	30.95
Electricity	18.180.22	MWh	18.180.22	25.82	644.633.47	18.90
Natural gas	1.242.602.50	Sm^3	11.506.50	16.34	180.614.51	5.30
Compressed air	49.932.20	$10^3 \cdot Nm^3$	9.487.12	13.47	575.456.84	16.87
Propane	73.80	t	952.02	1.35	56.610.55	1.66
Demi water	23.051.50	m^3			28.043.13	0.82
Water	679.120.00	m^3			378.767.57	11.11
TOTAL	–	–	70.414.35	100	3.410.208.37	100.00

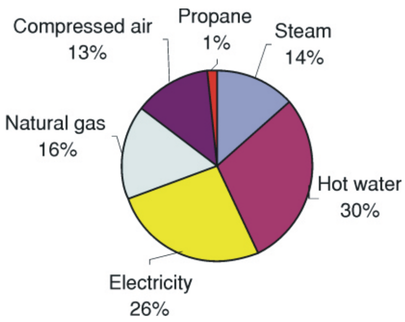

Figure 1. Proportion of energy sources in "Zastava Automobili" factory

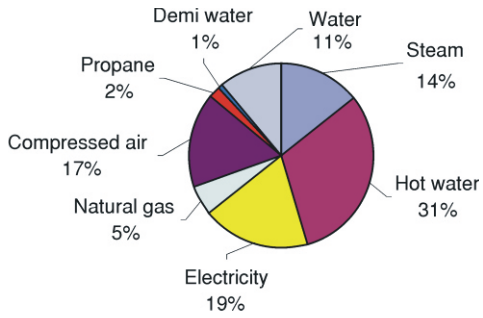

Figure 2. Proportion of energy costs in "Zastava Automobili" factory

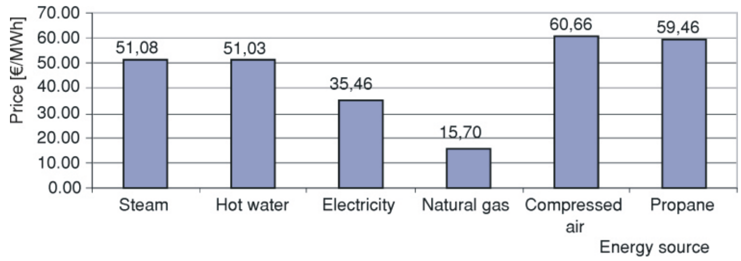

Figure 3. Average price of an energy source in "Zastava Automobili" factory

Beside the inadequate condition of energy equipment related to its age and improper maintenance, the high energy costs are also influenced with inadequate supplier's energy tariffs. The average tariffs of steam and hot water are 50% higher than average electricity tariff which should be the most expensive (fig. 3). Since the steam and hot water energy tariffs are 3.5 times larger than natural gas tariffs, in future reconstructions of the plants substitution of steam and hot water by natural gas should be anticipated.

Energy and water demand per certain product unit (specific energy and water consumptions – in the case of car manufacturing the unit is a produced car) are the best indicators of the efficiencies of energy supply and water supply systems. Average specific energy and water consumptions per unit of production in the analysed period were:

– specific steam consumption – 0.75 MWh per car
– specific hot water consumption – 1.33 MWh per car
– specific electricity consumption – 1.29 MWh per car
– specific natural gas consumption – 99.16 Sm^3 per car
– specific compressed air consumption – $3.54 \cdot 10^3$ Nm^3 per car
– specific water consumption – 44.51 m^3 per car
– specific demi water consumption – 1.65 m^3 per car
– specific propane consumption – 5.92 kg per car.

In "Zastava Automobili" factory, total specific consumption of heat energy (steam, hot water, propane, and natural gas) is approximately 3 MWh per car and specific electricity consumption (electricity and compressed air) is approximately 2 MWh per car. Accordingly to data of major car producers in USA and EU [1], their specific consumption of heat energy (fuel) is estimated on about 2 MWh per car and specific consumption of electricity is in range from 750 to 1.040 kWh (average is 0.87 MWh) so one can say that energy consumption of the factory is rather high.

Monthly consumption of energy sources and water (except the data for steam and electricity – fig. 4) plotted against monthly production of the factory presented in the audit are very scattered [6]. These results suggest that there is no proper monitoring of energy consumption and that energy management system can be improved.

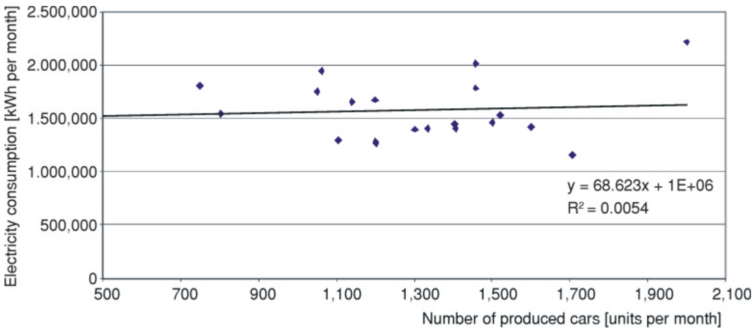

Figure 4. Monthly consumption of electricity as a function of monthly factory production

Relevant experiences from the comparing industry in USA are saying that the energy costs for the assembly of a car are approximately 60 $ per car [1]. Energy costs of the company "Zastava Automobili" in 2004 and 2005 were about 210 € per car including water costs (without water costs about 180 € per car). This unsuitable situation is partly influenced with the decreased usage of production capacities, but plenty possibilities for cost reduction exists.

Identification of energy saving measures

From the performed energy auditing, potential areas for energy savings were considered. Generally, an energy saving measure (ESM) can vary between simple low-cost measures (basic operation precautions and good housekeeping) and capital investments. ESM that were determined during the energy audit were the subjects of feasibility studies. The level of the study (preliminary or detailed) depends on the type of ESM. Even though the feasibility studies are based on the data obtained during the energy audit, in most cases, more measurement is necessary in order to realize estimations of actual benefits with satisfactory accuracy [3, 4].

The following text briefs selected energy saving measures recommended for the factory. The detailed feasibility studies can be found in project elaborates mentioned in references [7-12].

ESM No. 1. Detailed visual inspection and measurement with IC camera/IC thermometer revealed that: the maintenance of the insulation of steam and hot water pipelines is improper, some sections of the pipelines have poor insulation and significant sections do not have it at all. Analytically described there are approximately 750 m of inadequate insulated steam and hot water pipelines and total thermal energy loss on these sections is 251,695.23 kWh annually. It was calculated that with "properly" insulated pipelines (economic thickness of mineral wool in Al coil) the energy loss can be reduced on 13,721.55 kWh [7].

ESM No. 2. Considers the replacement of steam traps and the reconstruction of steam-condensate installation. The energy audit showed that all 22 steam traps were generally in bad condition, few of them were not functioning, some were damaged due to freezing and removed from the lines, condensate with "live steam" flowed through opened globe valve in by-pass lines (fig. 5) and few of them were not properly selected. According to performed calculations, the energy loss due to faulty steam traps is 9.932 MWh (app. 1.000 MWh) annually [7]. Therefore auditors proposed steam trap replacement with new properly dimensioned steam

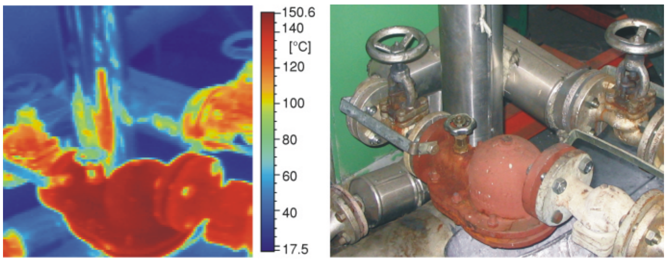

Figure 5. Using infrared thermography for diagnostic of steam traps

traps. Reconstruction of steam-condensate installation follows the steam trap replacement and includes: the use of flash steam for central low temperature heaters at finishing painting oven and the repair of incorrect condensate flow meter that register quantity of condensate which is returned back to steam supplier “Energetika”.

ESM No. 3. Instead of four finishing painting lines that were operative before 1999, only one production line remained in production process after the requisite modifications of the facility for car shell painting. Therefore, only air conditioners at prime painting lines were supplied with hot water from a technological hot water, THW 300, line. Since after plant modification the THW 400 hot water line became overdesigned, it was proposed to reconnect the air conditioners to the THW 400 line and to take out of service THW 300 line. In this way the THW 300 line that is 2.000 m long is completely disconnected from the system. This activity generates energy savings due to reduced hot water quantity in main lines that should be heated when prime painting line works (from September to May). Implementing this ESM the factory could save 1.066.28 MWh [7].

ESM No. 4. Energy auditors performed the inspection of the industrial lighting system and appropriate measurements of luminance with luxmeter. The analysis revealed that users (workers) were not satisfied with the level of luminance in the factory, windows and roof-lights were inaccessible and not regularly cleaned, high pressure mercury and fluorescent lamps were predominant and the maintenance and the control of industrial lighting system were at low level. It was recommended to replace high pressure mercury with high pressure sodium lamps, to relocate (bring down) fluorescent lamps from the ceiling, to introduce regular scheduled maintenance programme, to install occupancy sensors and time lighting control in few production lines. Approximately 180 MWh of electricity can be saved with these activities [8].

ESM No. 5. In order to establish the condition of electromotor drives in measurements with power analyzer were taken on 25 electromotors (ranging from 11 to 75 kW) selected by the energy manager. These electromotors drive fans at paint shop air conditioning chambers and pumps for ultra-filtration and for recirculation lines. They are more then 20 years old, relatively well maintained and rewound for several time. They are working in relatively constant regimes, so implementation of variable speed drive (VSD) would not be useful. Approximately 65% of analyzed aggregates are oversized (even two times then requested power) and many of them has power factor lower then 0.8. The implementation of proposed measures (replacing the oversized motors, installation of new high efficiency motors, correction of power factor [9]) should follow the replacement of existing electricity meters that register only consumption of active power on low voltage.

ESM No. 6. Series of measurement revealed that significant water consumption occurs in non-working time when there is no production in the factory [10]. Water pressure at the inlet of the factory varies in the range of 6-7 bar. Since the water pipeline system is relatively old and without adequate maintenance program in the last several years, it was proposed to install programmable hydraulic pressure regulator, at the inlet in order to maintain pressure at nonworking time at the level of 3 bar.

ESM No. 7. It was predicted to install 10 water meters at different plants in the factory so the water consumption in each of the plant can be monitored. The system of penalties and rewards that should be introduced can save at least 5% of consumed water in the factory [10].

ESM No. 8. The air leakage can be a significant source of energy loss in an industrial company. Between 20 and 50% of total produced compressed air leaks in a typically not properly maintained plant [5]. Leak repair and maintenance can reduce this number to less than 10%. The analysis of data from different production plants [11], showed that leak repair could reduce compressed air consumption in the factory by 20%, so the equivalent 1.897.42 MWh of electric energy can be saved. The estimation says that for this operation it is necessary to invest 85.000 € which gives payback time of less then 9 months [11].

ESM No. 9. The installation of six compressed air flow meters creates precondition for proper daily monitoring of compressed air consumption in each factory plant and localisation of eventual losses [11]. Total investment for the installation of the compressed air flow meters is 39.000 and expecting annual energy saving is $2.500 \cdot 10^3$Nm^3 of compressed air.

Table 2. Summary of ESMs in "Zastava Automobili" factory

No.	Name of energy conversion measure (ESM)	Annual energy saving	Financial effect of saved energy	ESM cost (including maintenance costs)	Payback time	
					Years	Months
1	Pipeline insulation	237.98 MWh	11.608.47 €	8.683.40 €	0.75	9
2	Steam trap replacement	1.000.00 MWh	55.000.00 €	5.500.00 €	0.10	1.2
3	Reconnection of TVV 300 hot water pipeline	1.066.28 MWh	52.204.56 €	24.539.88 €	0.47	5.64
4	Reconstruction of the industrial lighting system	180 MWh	9.000.00 €	14.400 €	1.6	18
5	Maintenance of electromotor drives	200 MWh	10.500.00 €	19.300.00 €	1.84	22.08
6	Installation of programmable hydraulic pressure regulator	280.000 m^3	159.600.00 €	21.090.91 €	0.13	1.6
7	Introducing water meters					
8	Compressed air leakage reduction	1.897.42 MWh	115.091.37 €	85.000.00 €	0.74	8.86
9	Introducing compressed air flow meters	474.36 MWh	28.772.84 €	30.000.00 €	1.04	12.51
10	Construction of new compressed air generating system	–	247.278.75 €	894.000.00 €	3.62	43.38
11	Construction of new boiler house	–	910.000.00 €	2.360.000.00 €	2.59	31.12

ESM No. 10. Compressed air is one of the main energy sources in the factory. Due to high price of compressed air (fig. 3) it was proposed to install a new compressed air generating system. Based on following factors and presumptions: the location of the facilities, data on air demands of the facilities, 30% reserve in the capacity and that all leaks are repaired it was proposed to install two new compressor stations [11]. At both locations non-lubricated water-cooled rotary screw compressors that deliver oil free air were selected. At each of compressor stations one of the compressors has variable speed drive. With this ESM the factory does not save energy directly but total energy cost can be significantly reduced.

ESM No. 11. Due to many problems in distribution of hot water and steam it was proposed to construct a new boiler house. Analysing the real consumption in the last several years and taking into account properties of the facilities that use hot water and steam it was proposed to build a new boiler house. Two hot water boilers capacities of 16 and 8 MW were proposed [12]. Since air conditioning plants at the prime and finish painting lines do not operate during summer, for hot water production only the 16 MW boiler should be used during this period. When facilities in "Object A" operate only the 8 MW boiler should be used. During winter time, both boilers should be used. Considering production process in the factory one steam boiler with output power 8 MW (11.2 t per hour of steam, 250 °C, pressure 15 bar) was predicted.

The summary of all proposed ESM with basic technological and economical indicators is shown in tab. 2

Implementation, monitoring, and evaluation of energy saving measures

The implementation of ESM is normally the responsibility of an energy manager [2]. Its task is to establish a proper communication with the management in order to provide proper financial and any other support. Once a choice of the energy saving measures has been made (based on their technical and economic feasibility) energy manager could start to implement these options into practice and to monitor the results.

Monitoring facilitates keeping track of the energy consumption of the factory, and evaluation over a period of time gives an indication of the success or failure of the ESM. It helps to judge whether the predicted energy savings are actually being achieved or not. It will also assist in identifying alternate adjustments and new possibilities. Periodic monitoring requires some measuring equipment and maintaining energy record [5, 13].

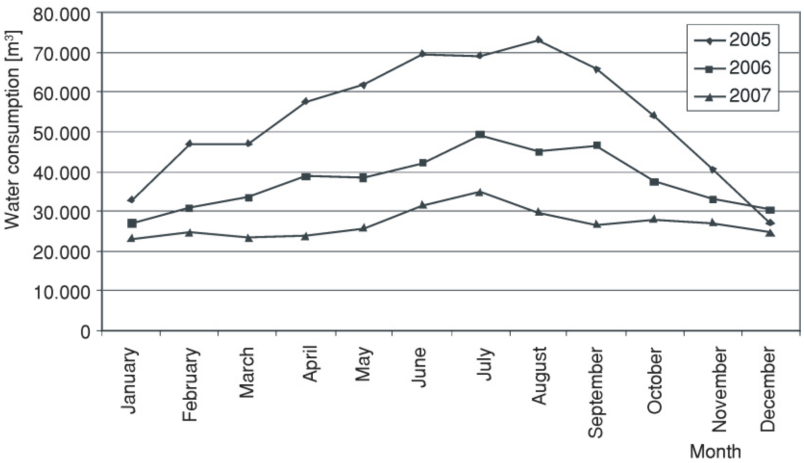

Figure 6. Comparison of water consumption in "Zastava Automobili" factory in 2005-2007

Although all proposed ESM were not implemented yet, significant results were already achieved with implemented ones. The illustrations of effectiveness of implemented ESM are diagrams of water consumption (fig. 6) and thermal energy consumption (fig. 7) for the last three years. It should be mentioned that annual production in the factory was practically at the same level. Total water consumption was decreased for almost 50% (about 300.000 m^3) what made company saved over 220.000 €. Heat energy consumption was decreased for over 20% (about 9.000 MWh) which reduced 350.000 € of heat energy costs.

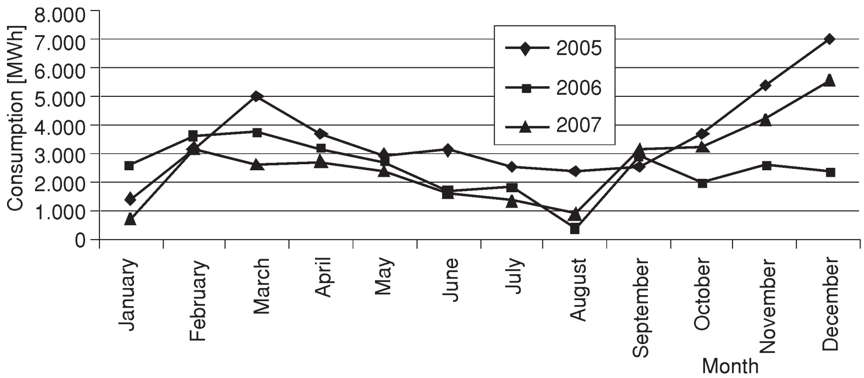

Figure 7. Comparison of heat energy consumption in "Zastava Automobili" factory in 2005-2007

New compressors are operative since October 2007. In comparison with previous situation, compressed air has higher quality, the air supply is without unpredicted terminations and the compressors work without unexpected costs. Only in period January-May 2008, the operation of the new compressor stations reduced more then 170.000 € of energy costs.

Conclusions

The design of a strategic energy programme in an industrial company starts from the energy audit – the analysis of the present energy supply and consumption situation. As a result of the energy audit in "Zastava Automobili" factory, energy saving measures that have relatively fast payback time were suggested. Approximately a reduction of 25% of total energy consumption was obtained as a result of the introduction of proposed ESM in different facilities in the "Zastava Automobili" factory.

Most of the proposed measures are not exclusively related to car production facilities; they are universal and with minor modifications can be applied to other industries. As manufacturers face an increasingly competitive environment, proposed ESM can provide a mean to reduce production costs without negatively affecting the yield or the quality of final products.

Acknowledgment

This research has been financed by Ministry of Science of Republic of Serbia in the frame of National Energy Efficiency Program, project No. NPEE 232007 "Energy Balancing and Energy Cost Reduction in Zastava Automobili" (Development program: Energy efficiency in industry). Research has also been supported by "Zastava Automobili" factory.

References

[1] Galitsky, C., Worrell, E., Energy Efficiency Improvement and Cost Saving Opportunities for the Vehicle Assembly Industry, An ENERGY STAR® Guide for Energy and Plant Managers, Ernest Orlando Lawrence Berkeley National Laboratory, Berkeley, Cal., USA, 2003

[2] Thumann, A., Youngeer, W. J., Handbook of Energy Audits, 6th ed., The Fairmont Press Inc., New York, N. Y., USA, 2003

[3] Capeheart, L. B., Turner, W. C., Kennedy, W. J., Guide to Energy Management, The Fairmont Press and Marcell Dekker Inc., 4th ed., New York, N. Y., USA, 2003

[4] Turner, W. C., Energy Management Handbook, 3rd ed., The Fairmont Press Inc., USA, 1997.

[5] Thumann, A., Plant Engineers and Managers Guide to Energy Conservation, The Fairmont Press and Marcell Dekker Inc., New York, N. Y., USA, 2002

[6] Gordić, D., *et. al.*, Energy Auditing of Zastava Automobili Factory (in Serbian), Elaborate #1/2007 of Project NPEE 232007: Energy Balancing and Energy Cost Reduction in Zastava Automobili Factory, Faculty of Mechanical Engineering, University of Kragujevac, Kragujevac, Serbia, 2007

[7] Gordić, D., *et. al*., Definition and Techno-Economic Evaluation of Measurements for Reduction of Costs of Hot Water and Steam in Paint Shop of "Zastava Automobili" (in Serbian), Elaborate #2/2007 of Project NPEE 232007: Energy Balancing and Energy Cost Reduction in Zastava Automobili Factory, Faculty of Mechanical Engineering, University of Kragujevac, Kragujevac, Serbia, 2008

[8] Gordić, D., *et. al*., Increase of Energy Efficiency of Industrial Lighting System in "Zastava Automobili" (in Serbian), Elaborate #2/2008 of Project NPEE 232007: Energy Balancing and Energy Cost Reduction in Zastava Automobili Factory, Faculty of Mechanical Engineering, University of Kragujevac, Kragujevac, Serbia, 2008

[9] Gordić, D., *et. al*., Analysis of Electromotor Drives in "Zastava Automobili" (in Serbian), Elaborate #3/2008 of Project NPEE 232007 : Energy Balancing and Energy Cost Reduction in Zastava Automobili Factory, Faculty of Mechanical Engineering, University of Kragujevac, Kragujevac, Serbia, 2008

[10] Gordić, D., *et. al.*, Measurement of Water Consumption and Possibilities for the Reduction of Water Costs in Zastava Automobili Factory (in Serbian), Elaborate #6/2007 of Project NPEE 232007: Energy Balancing and Energy Cost Reduction in Zastava Automobili Factory, Faculty of Mechanical Engineering, University of Kragujevac, Kragujevac, Serbia, 2007

[11] Gordić, D., *et. al*., Data Analysis and Definition of ESMs for Better Energy Management of Compressed Air in Zastava Automobili Factory (in Serbian), Elaborate #5/2007 of Project NPEE 232007: Energy Balancing and Energy Cost Reduction in Zastava Automobili Factory, Faculty of Mechanical Engineering, University of Kragujevac, Kragujevac, Serbia, 2007

[12] Gordić, D., *et. al.*, Construction of New Boiler House in "Zastava Automobili" (in Serbian), Elaborate #4/2008 of Project NPEE 232007: Energy Balancing and Energy Cost Reduction in Zastava Automobili Factory, Faculty of Mechanical Engineering, University of Kragujevac, Kragujevac, Serbia, 2007

[13] Kannan, R., Boie, W., Energy Management Practices in SME: Case Study of a Bakery in Germany, *Energy Conversion and management, 44* (2003), 6, pp. 945-959

Authors´ affiliations:

D. R. Gordić (**corresponding author**)
Faculty of Mechanical Engineering, University of Kragujevac,
6, Sestre Janjić Str., 34000 Kragujevac, Serbia
E-mail: gordic@kg.ac.yu

M. J. Babić, D. N. Jelić, D. M. Končalović, N. M. Jovičić, V. Šušteršič,
Faculty of Mechanical Engineering, University of Kragujevac,
Kragujevac, Serbia

Paper submitted: September 9, 2008
Paper revised: September 17, 2008
Paper accepted: January 29, 2009