Analysis of energy efficiency of an industrial system

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Abstract: Survey energy efficiency of an industrial system was done. On the base energy audit, the consumption of energy and water was made analyse. On the following audit, there were made choices of energy saving measures, which would lead to proving and economy of energy in the industrial system and condition to work. The ultimate and primary energy savings for the industrial system, as well as CO₂ emissions, were determined.

1. Introduction
Decreasing consumption and loss of energy are current problems with global importance [1]. Steps for the raise of energy efficiency more often considered as a means not only of achieving a sustainable energy supply, reduction of greenhouse gas emissions, increase the security of supply and reduce import costs but also to increase the competitiveness of national economies [1, 2].

In front of the development of a leading economy in the European Union, there are three main challenges: change in climate, dependence on energy reserves, and high electricity values. This is connected with questions of energy efficiency which occupy an important place in the legal policy of the member states of the European Union for deciding the right use of energy [3, 4].

The developed energy audits lead to a decrease in energy consumption of the manufacturing system generally. They are established by the survey activities and give the information on which activities to focus attention and which enhancement measures should be taken to increase energy efficiency. An assessment of the most cost-effective measures is carried out which means that by the least investment should be achieved energy savings as keep quality of the production [5-9, 11-13].

Energy saving in industrial enterprises is one of the important problems in the modern industry. This is due to the permanent increase in the price of electricity and other energy sources [4].

One of the main premises for reducing costs in industrial production enterprises and increasing economic efficiency is the rational use of energy resources. The energy saving dispositions that taken are designed to ensure a significant reduction in energy costs. Thereby there is an opportunity to achieve positive technical and economic indicators in industrial enterprises and improving the environmental and economic situation. In view of the above, this article analyzes a survey of an industrial enterprise and provides specific solutions to reduce the energy costs of a machine-building enterprise, as well as
determines the final and primary energy savings from the application of energy saving measures, and also calculates CO$_2$ emissions.

2. Materials and methods
In many cases, the main factor for energy consumption in production systems is the amount of production which is a variable over time. The total effect of the application of energy saving measures cannot be defined as an additive quantity of the separate measures. There are many reasons: it is not possible to identify single effects or the identification of the mutual influence in one package of measures, and the changing of the main factor. The amount of production significantly affects the magnitude of the single and joint effects. The proposed methodology includes calculation of the saved final and primary energies, as well as a calculation of the ecological effect - CO$_2$ emissions [5, 10]. The algorithm includes the following steps presented by authors [5, 10, 11, 14, 15]:

- A base year for the start of the evaluation is determined. For the base year, the specific final energy consumption for the specific product for each used energy resource is calculated on the basis of measured data for the year. In the cases when from the product a residual mass of the raw material is obtained it is processed into an additional other product. For this product, it is impossible precise determination of energy consumption and the release of total energy for the whole process. The quantity of the product can be determined as the equivalent total quantity.
- The energy savings when using a number of different energy resources during the estimated period are determined.
- When using a number of different energy resources during the estimated period, the ecological equivalent of the saved energy from the application of energy saving measures for all energy sources is calculated.

3. Results and discussion
An industrial system was audited for the production of aluminum profiles and foil. The prime materials are produced from aluminum. The final product is the aluminum foil and aluminum profiles.

The main technologies in this type of production are melting of aluminum charge in flame-reflecting furnaces, mixing in a mixer, addition of ligatures, cold-roll drawing of degrees depending on the desired final thickness, annealing in electro-resistance furnaces; pressing in presses to desired profiles, artificial aging in furnaces; anodizing, powder coating, etc.

In Table 1 are shown data for the annual consumption of the consumed amount of fuel and electricity from the enterprise for 2006. This is the year preceding the energy audit.

| Energy Resource    | Annual Energy Consumption | Basic Energy Consumption |
|--------------------|----------------------------|--------------------------|
| kind of the resource | kg/year       | nm$^3$/year | kWh/year | kWh/year |
| 1 | Oil  | 0 | |
| 2 | Diesel Fuel |  |  | |
| 3 | Propane-Butane |  |  | |
| 4 | Natural Gas | 8411000 | 78223040 | 78223040 |
| 5 | Industrial Gazelle |  |  | |
| 6 | Coke | 0 |  | |
| 7 | Coal | 0 |  | |
| 8 | Others (Feed Water) | 21140 | 21140 | |
| 9 | Thermal Energy | 0 |  | |
| 10 | Electrical Energy | 54575401 | 54575401 | |
| **Total:** | 132819581 | 132819581 | |

Table 1. Annual fuel and energy consumption for the year preceding the survey.
In the production was used the following energy carriers: natural gas, water and electricity. Figure 1 is presented the consumption in the percents on each of the energy carriers.

![Figure 1](image)

**Figure 1.** Main energy sources in the industrial system.

The total electricity consumption of the enterprise by months for the period from 2007 to 2009 is presented in Table 2. The monthly consumption of electricity depends on the production for different years in the percentage consumption of electricity differs for a given month. Characteristic for the considered period of time for the three years the highest electricity consumption is in the months of April to November, and the lowest consumption in the months of December to March, which corresponds to the amount of production.

**Table 2.** Monthly electricity consumption in kWh.

| Month    | 2007    | 2008    | 2009    | on average per month |
|----------|---------|---------|---------|----------------------|
| January  | 348562  | 291792  | 440608  | 5.3%                 |
| February | 362866  | 353976  | 388556  | 5.4%                 |
| March    | 395823  | 343633  | 508360  | 6.1%                 |
| April    | 596916  | 568096  | 516540  | 8.3%                 |
| May      | 777537  | 417679  | 542268  | 8.6%                 |
| June     | 887846  | 452489  | 671012  | 9.9%                 |
| July     | 621366  | 607516  | 678460  | 9.4%                 |
| August   | 750368  | 741108  | 717552  | 10.9%                |
| September| 909757  | 890616  | 707968  | 12.3%                |
| October  | 719829  | 699439  | 699412  | 10.4%                |
| November | 598736  | 588696  | 699280  | 9.3%                 |
| December | 286599  | 280192  | 258020  | 4.1%                 |
| TOTAL    | 7256205 | 6235232 | 6828036 | 100.00%              |

Based on the energy consumption for three years (2007-2009), the specific consumption of electricity per unit of production for the considered years was determined. Based on the specific energy consumption in the survey of the industrial system, a graphical dependence was constructed in Figure 2, which reflects the specific consumption of electricity for a year, and also gives an estimated value of the specific consumption. The linear regression equation was presented for the calculation of specific consumption in the future. On the basis of the presented data, the correlation coefficient was determined, $R^2 = 0.707$. 
$y = -211692.50 + 106.93 \cdot x$  \hspace{1cm} \text{(1)}$

where: $x$ - is the year for which the estimated value will be determined; 
$y$ - is the specific consumption of electricity consumed per unit of product.

**Figure 2.** Specific electricity consumption for the final product.

The specific electricity consumption was presented on the basis of a finished product and depended on the electricity consumption for the year and the production obtained for the same year. As can be seen from the graphical dependence, for the first year (2007) the highest consumption was observed and the lowest – for the second year (2008). It was due to the lower electricity consumption in the first year, as well as the little production for the second year. The obtained results lead to the conclusion that the value of the consumed electricity is mainly influenced by the production program of the enterprise. Traditionally, in the months of March – November there is higher sales, higher production volume, and consequently higher electricity consumption. The influence of the annual seasons mainly affects the operation of the technological cooling system – the refrigeration installations (total installed capacity of the chillers together with the pumping units 511 kW), providing cooling of circulating water for technological needs, during the summer months they work with a higher load compared to the winter months. With a reduced volume of production in the months of December-January, the cooling of the circulating water is carried out mainly by a water cooling tower. It was found that the average specific consumption of electricity for the finished product for the three years was 3017.92 kWh / t, and for 2007 is 2871.25 kWh / t, which was below the average consumption for the three years.

Based on the presented data on the energy consumption of the production enterprise for 3 years (Table 2), the energy consumption for 2006 (Table 1) and data on the processed products and the final products, the specific electricity consumption was determined (from two energy sources – electricity and natural gas). The total saved final and primary energy in the production of the final product for the reporting period as well as the ecological effect of the saved CO$_2$ emissions were calculated. The results of the calculations are presented in Table 3.

Based on the performed energy audit and the energy balances of the considered enterprise, the following energy saving measures were prescribed:

- Replacement of existing condensing pots (the level of condensate in the coils of the anodizing baths is lower than the level of the condensate pots, which does not allow all the condensate to drain from the coils. This reduces their effectiveness).

- It was proposed to replace the existing condensing pots with condensing pots of the type “steam lock release (SLR)”, which are specially designed to be located above the steam consumer.
It was proposed the install 6 pcs. BA-2, which work with a common condensing pot, which leads to their intermittent load.

- It was proposed to install a separate condensing pot on each of the air heaters.
- It was proposed to replace the old, depreciated CG with new ones of the other steam consumers (the proposed measure is based on a technical and economic calculation, determining the losses, the required capital investments and the terms of ransom).

| Month     | Saved final energy by years, MWh | Saved primary energy by years, MWh | Saved CO₂ emissions by years, t CO₂/MWh |
|-----------|----------------------------------|------------------------------------|-----------------------------------------|
| January   | 610                              | 2869                               | 3296                                    |
| February  | 785                              | 1276                               | 7856                                    |
| March     | 615                              | 2526                               | 2536                                    |
| April     | 800                              | 1675                               | 2610                                    |
| May       | 1000                             | 1286                               | 2470                                    |
| June      | 900                              | 1126                               | 1865                                    |
| July      | 750                              | 1609                               | 2110                                    |
| August    | 745                              | 1333                               | 1800                                    |
| September | 980                              | 1099                               | 2187                                    |
| October   | 780                              | 1389                               | 1907                                    |
| November  | 940                              | 1670                               | 3223                                    |
| December  | 1350                             | 3489                               | 13887                                   |
| TOTAL     | 855                              | 22829                              | 43392                                   |

Based on the analysis of the state of the energy system, it is established that the company monitors energy efficiency and takes necessary measures to reduce energy consumption.

4. Conclusion
Based on an energy efficiency survey of an industrial enterprise for the production of aluminum profiles, the saved final and primary energy are calculated depending on the energy sources used. The ecological effect was determined as a result of the applied survey and CO₂ emissions were determined on the basis of the two energy sources used (electricity and natural gas). A forecast equation for deriving the specific consumption of electricity per unit of product is derived.

References
[1] Energy Strategy of the Republic of Bulgaria until 2020 (SG No. 43), 12-25
[2] Energy Efficiency Act (promulgated, SG No. 35 of 15.05.2015, amended and supplemented, SG No. 38 of 08.05.2018, in force since 8.05.2018)
[3] Tsvetanov, P., G. Stoiilov, L. Adzharova, G. Bosev, Electroenergy of Bulgaria, 2010, Energy Forum, pp. 1-9
[4] Baev, D., Energy efficiency management in industrial enterprises, 2014, Conference for presentation of the project "Increasing the institutional capacity of the Agency for Sustainable Energy Development in order to provide more and better services in the field of energy efficiency", pp.1-43
[5] Kaloyanov, N., One approach to the assessment of savings in the industrial system as a result of multiconnected energy saving measures, 2017, Scientific Conference EMF-2017, vol.1, pp.118-123
[6] Kamburova, V., I. Iliev, M. Velikanov, A. Terziev, A. Ahmedov, K. Iliev, Energy efficiency of large industrial enterprises, 2017, Energy, vol.3, pp.40-50
[7] Simeonov, R., Study of the influence of technical factors on the processes of integration of the energy systems of the Balkans, 2019, Computer Science and Communications, vol. 8, No1, pp.48-53

[8] Draganescu, F., M. Gheorghe, C. Doicin, Models of machine tool efficiency and specific consumed energy, 2015, Journal of Materials Processing Technology, vol.141, No. 1, pp.9-15

[9] Ivanov, K. B. Tonkovski, Energy consumption and energy efficiency of machine tools – an overview, 2018, Proceeding of University of Ruse -2018, vol.57, b. 1.2, pp.83-88

[10] Kaloyanov, N., An approach to calculating energy savings in a greenhouse complex, 2018, Reports of "Energy, ecology, comfort, well-being" EMF 2018, pp. 68-77

[11] Iliev, I., N. Kaloyanov, P. Gramatikov, A. Terziev, I. Pavlov, S. Stefanov, K. Sirakov, V. Kamburova, Handbook of Energy Efficiency and Energy Management, 2013, Energy Efficiency and Green Economy Program, pp.1-225

[12] Valchev, G., 2010 Scientific Conference, Energy efficiency and environmental protection, 2010, University of Canak Kale, Turkey, 1109-1119

[13] Kesova, P., I. Bachkova, 2015 XXIII International Symposium - Management of Energy, Industrial and Ecological Systems, pp.91-94

[14] Ordinance № Е-RD-04-3 of 4.05.2016 on the admissible measures for implementation of energy savings in final consumption, the ways of proving the achieved energy savings, the requirements to the methodologies for their evaluation and the ways for their confirmation

[15] Ordinance № е-rd-04-05 of 8 September 2016 on determining the energy consumption indicators, energy performance of enterprises, industrial systems and outdoor artificial lighting systems, as well as on determining the conditions and procedure for conducting inspections for energy efficiency and preparation of energy savings assessment