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Energy balance and analysis of the possibilities of implementing cogeneration in a textile plant

Abstract: Cogeneration is one of the leading technologies. Over time, it has been activated by almost all developed and actively developing countries in the world. However, achieving high energy efficiency when investing in such production is not an absolute rule but a matter of a thorough technical and economic assessment of the existing conditions. The management teams of textile enterprises usually focus on improving the economic and operational results, but despite the benefits of cogeneration, they do not want to take risks in its implementation because it is related to large strategic investments in the sector. Conducting research to identify and analyze the specific operating conditions of the textile enterprise in question will allow for the analysis of the possibility of introducing cogeneration. Looking at the structure of the energy consumption of the two types of energy (heat and electricity), the dynamics of prices and the geographical location are a prerequisites for studying the possibilities of introducing joint production of heat and electricity at a large textile enterprise. In the publication, an analysis of primary energy consumption was performed, a heat balance of the considered enterprise was drawn up, and objective economic and technical parameters based on the characteristics of the technology were derived. Based on the analysis of the obtained results, conclusions have been drawn regarding the possibilities of implementing joint extraction of heat and electricity in textile enterprises. The scientific novelty has been demonstrated by applying

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a new approach for a complete solution, aiming to achieve cleaner production and increase the energy efficiency of the considered textile enterprise.

Keywords: cogeneration, textile plant, energy balance, structure of energy consumption

Introduction

The Bulgarian industry and textile enterprises, in particular, are located at crossroads caused by the great dynamics of technological innovations continuously entering the industry (Oliveira Neto et al. 2023; Kluczek and Buczacki 2023; Garcia et al. 2024). The efficient conversion and use of energy through cogeneration are well known to provide significant primary energy savings in terms of separate production of the same amount of heat and electricity compared to conventional sources (Saini and Jakhar 2024; Zaporowski 2019; Stós et al. 2019). Even better primary energy use results are achieved in local cogeneration plants. With this technology, electrical energy and heat are obtained directly from the user, whereby energy systems can be optimally adapted to their specific requirements and needs (Jing Gao et al. 2024; Hirvonen et al. 2014). Energy transmission losses are reduced, and equipment efficiency is increased. In addition, this energy production technology is significantly safer for the environment than most conventional technologies, especially when using natural gas (Ali et al. 2023a). Compared to the production of electricity and heat from thermal power plants burning coal or fuel oil, harmful CO_2 emissions can be reduced by more than 50%, by -NOx by about 30%, by SOx – by 98%. Cogeneration systems can help businesses meet national and international obligations to reduce harmful emissions into the atmosphere (Mancarella and Chicco 2009), such as meeting the limits for air toxins from steam boilers, as cogeneration systems and waste energy recovery systems meet clean energy standards. While these systems alone cannot bring businesses into compliance with the restrictions, they can, in practice, help reduce the cost of meeting these standards and reduce harmful emissions released into the air (Park et al. 2015; Iliev et al. 2020).

Investing and putting the cogeneration plants into operation, on the other hand, and analyzing the economic situation in the Republic of Bulgaria depends on energy prices, capital, operating costs, and maintenance costs of the installations (Khan et al. 2023; Andreas et al. 2018). The implementation of each such installation involves a thorough technical-economic analysis and includes the integration of the relevant technical and economic factors (Iliev et al. 2023; Gładysz et al. 2020).

In order to perform an energy consumption analysis, it is important to introduce a single criterion by which energy consumption can be evaluated. The introduction of such a criterion should represent a set of used energy resources, referred to as a finished product or raw material (Wen et al. 2021). In practice, all types of energy carriers, such as heat supplied by steam and hot water, electrical energy of all voltage levels, technical air, etc., must be converted to an equivalent value.

When drawing up the energy balance (Khurana et al. 2002), there are requirements for it, which can be summarized by the following factors:

- the information is presented in such a way as to give an idea of the efficiency – it is necessary to separate the components of the useful energy from the energy losses from the energy consumption;
- to reflect the target, use of energy carriers by process – technological, power, heating, ventilation, lighting, utility sector;
- to reflect internal factory production – territorial distribution of energy carriers;
- to reflect internal turnover of energy – by types and parameters of energy carriers;

In addition to market parameters, the reliability and risk associated with cogeneration investments are further determined by the correct sizing of the installations (Ali et al. 2023b; Zhang et al. 2023). In the textile sector, when new cogeneration projects are discussed, a technical analysis should be carried out in terms of primary energy savings and the possibility of future expansion of the industrial unit before their implementation so that the sizing of the co-generator corresponds to the actual electricity and heat needs of the enterprise. The preparation of a complete and accurate analysis of energy consumption allows the cogeneration installations to be sized according to the consumption of electricity or thermal energy. It is typical for textile enterprises that the required power of the cogeneration plants must be based on the heat demand of the industrial facilities. In this way, the surplus of the generated electricity can be sold in the country's electricity market.

Based on this, the publication presents an energy balance and analyses the possibilities for implementing cogeneration in the considered textile enterprise. In addition to the significant factors that are indicated in the analysis, the possible consequences from an economic point of view are also indicated.

1. Materials and methods

The textile enterprise, the object of research and analysis in this publication, was established in 2002 and its main activity is the production of woollen fabrics and yarns. To carry out the production processes and cover the heating and domestic hot water supply needs, a steam plant was built at the enterprise. Four boilers for the production of technological steam with parameters are installed and working in it $T = 180°C$ and $P = 10$ Bar. The boilers implemented in production are – two with steam productivity of 10 t/h, one with 7 t/h and one with steam productivity of 5 t/h. They are all connected for operation in parallel with a common collector. Automatic ignition of each of them depends on the need for steam at a given time. The produced steam feeds all the main productions that consume steam both for their technological processes and for the operation of the air-conditioning installations designed to maintain certain operating parameters of the air specific to each of the productions. Steam supply is carried out through separate steam pipelines to each main production. The heating and domestic hot water needs of the "secondary" consumers are covered by the heat of the condensate, which is distributed from the main subscriber station through collectors to them. In addition to its own needs, the heat farm of the textile enterprise in question produces and supplies steam to an external user located in the area of the enterprise. For the needs of this external company, 5 t/h of steam is supplied all year round.

The presented load schedules for the annual electricity, steam, and natural gas consumption for the last five years, and the data indicated in the tables are averaged over the same period.

Table 1. Average electricity consumption for the last five years

Tabela 1. Średnie zużycie energii elektrycznej w ciągu ostatnich pięciu lat

January	February	March	April	May	June	July	August	September	October	November	December
MWh	MWh	MWh	MWh	MWh	MWh	MWh	MWh	MWh	MWh	MWh	MWh
2,108.7	2,839.6	3,173.9	2,574.9	3,209.1	2,984.2	3,126.1	3,153.7	2,698.9	3,190.1	2,932.7	1,794.5

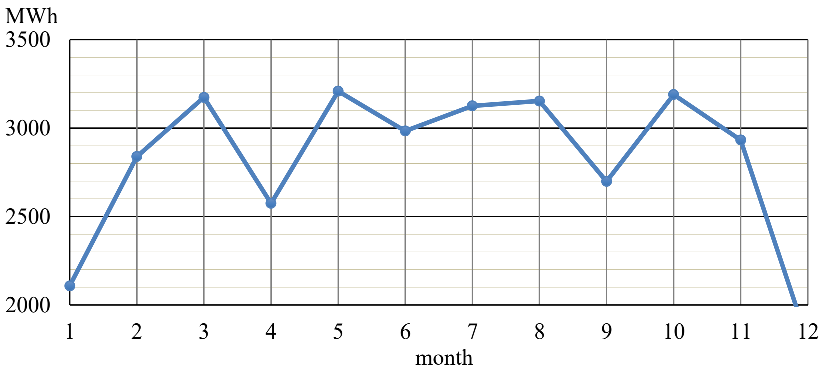

Fig. 1. Graphical representation of the average electricity consumption for the last five years

Rys. 1. Graficzne przedstawienie średniego zużycia energii elektrycznej w ciągu ostatnich pięciu lat

The load chart is relatively even, with typically higher values in the first and last quarters of the year. For the month of December, a certain drop in the electric and heat load is noticeable, which is explained by the suspension of the work of the entire enterprise around the Christmas and New Year holidays.

From the load schedules, it can be concluded that the steam plant operation will be relatively constant over time. This gives reason to assume that cogeneration energy capacities implemented in the enterprise's heat supply system would yield a significant positive result. This undeniable effect can be achieved in several directions:

Table 2. Average steam consumption for the last five years

Tabela 2. Średnie zużycie pary w ciągu ostatnich pięciu lat

January	February	March	April	May	June	July	August	September	October	November	December
MWh	MWh	MWh	MWh	MWh	MWh	MWh	MWh	MWh	MWh	MWh	MWh
6,645	6,645	6,020	4,185	4,180	3,932	3,523	3,800	3,548	4,348	6,301	4,836

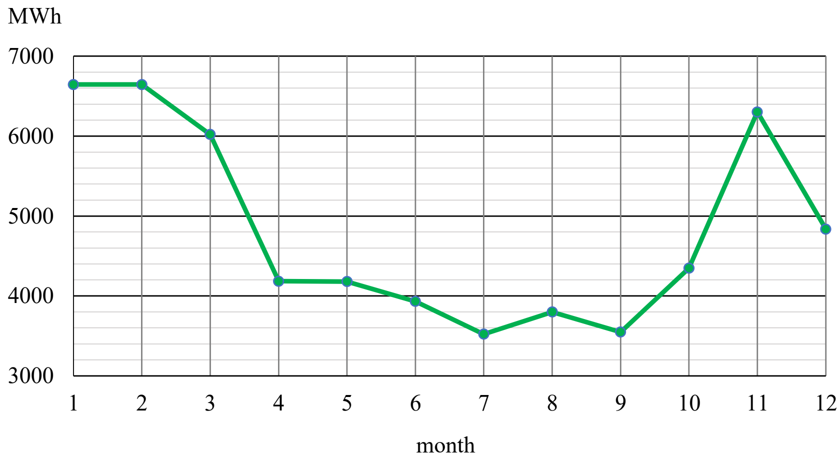

Fig. 2. Graphical representation of the average steam consumption for the last five years

Rys. 2. Graficzne przedstawienie średniego zużycia pary w ciągu ostatnich pięciu lat

- the year-round supply of heat carriers for technological needs and heating will be accompanied by the extraction of electricity, the surplus quantities of which will be sold on the free energy market;
- the peak periods of steam consumption will be covered by the available steam boilers and will have guaranteed electricity output from the co-generator;
- the heat supply system will become significantly more independent in terms of operation and from the outdated energy equipment.

The sizing of the cogeneration system should be carried out after a precise calculation, which is aimed at determining the optimal parameters of the individual components. Based on the enterprise's specified load schedules, an energy scheme analysis was carried out and the possibilities of applying cogeneration were evaluated. When sizing the new installation, the aspiration is to achieve the maximum useful result with a minimum installed power, thus achieving economical operation and high efficiency.

Table 3. Average natural gas consumption for the last five years

Tabela 3. Średnie zużycie gazu ziemnego w ciągu ostatnich pięciu lat

January	February	March	April	May	June	July	August	September	October	November	December
nm^3	nm^3	nm^3	nm^3	nm^3	nm^3	nm^3	nm3	nm^3	nm^3	nm^3	nm^3
1,024,000	1,055,000	980,000	719,000	708,000	669,000	676,000	681,000	632,000	728,000	926,000	699,000

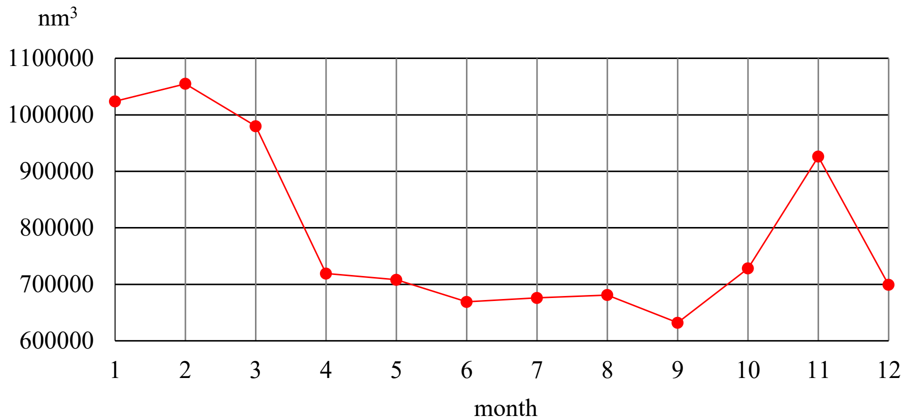

Fig. 3. Graphic representation of the average consumption of natural gas for the last five years

Rys. 3. Graficzne przedstawienie średniego zużycia gazu ziemnego w ciągu ostatnich pięciu lat

2. Discussion

There are two fundamentally different approaches to sizing cogeneration systems – the first is based on satisfying heat energy needs, and the second is based on electricity needs.

When sizing according to the first method, it is necessary to analyze the annual heat energy needs and to plot graphically the dependence of the required average heat output on the duration in hours (Fig.4). The area bounded by the coordinate axes and the graphic curve will be equal to the required thermal energy. From this dependence, the maximum power of the cogeneration plant is selected, which is usually in the range of 30 to 50% of the maximum average thermal power. It can be seen from the figure that such power provides about 60–70% of the required heat energy. The remaining 30–40% is provided by steam boilers used only during peak load periods. Since the enterprise in question is a textile with a continuous operation process, the main condition for the implementation of the cogeneration system, according to its heat and steam needs, is met. The generated electricity should be consumed without limit. In the case of a surplus, it will be sold on the energy market.

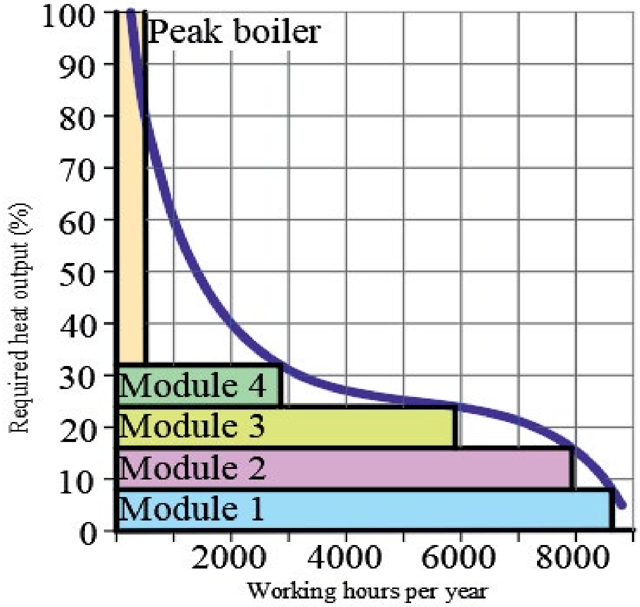

Fig. 4. Dependence between average heat output and working hours

Rys. 4. Zależność między średnią mocą cieplną a godzinami pracy

When the cogeneration systems are sized on the basis of electricity consumption, the co-generators' power and duration of operation should be calculated so that a certain amount of electricity is obtained and the thermal energy is fully used. In addition, if in a certain period of time heat energy is produced in excess of the required amount, the excess amount can be stored for a short period of time in a heat accumulator (if possible) or thrown away unused. In the latter case, there will be a loss of energy and funds in the textile enterprise in question.

From the analysis of the data from the conducted energy balance, according to dependency 1, the average heat load of the heat supply installation can be determined:

$$Q = b_m H_u \eta \quad [\text{kW}] \tag{1}$$

where:

- b_m – instantaneous consumption of natural gas [m^3/s],
- H_u – lower heat of combustion of fuel (natural gas) [kJ/m^3],
- η – efficiency factor of the heat supply installation, defined as the ratio of the average monthly consumption of steam, referred to as the thermal equivalent of natural gas consumption.

Based on the design calculations, Figure 5 presents the heat balance of a cogeneration module. It is important to note that a recovery boiler (steam generator) with a capacity of 6.65 MW is also needed, which will satisfy the needs of the enterprise with process steam. Regarding the necessary reorganization of the heat scheme of the enterprise in question, it seems a better option to include two cogeneration modules in the existing scheme, which will fully cover the enterprise's needs for processing steam and hot water. Taking into account the losses in the steam pipelines during the transfer of steam to the main productions, which worsen the parameters of the produced process steam, the possibility of installing local boiler installations to each production should also be considered. This would increase the capital investments of the enterprise, but it will improve the parameters of the technological steam entering the individual productions, which, in turn, will increase the quality of the technological processes and the output produced by the enterprise. The available steam boilers will cover the peak load periods.

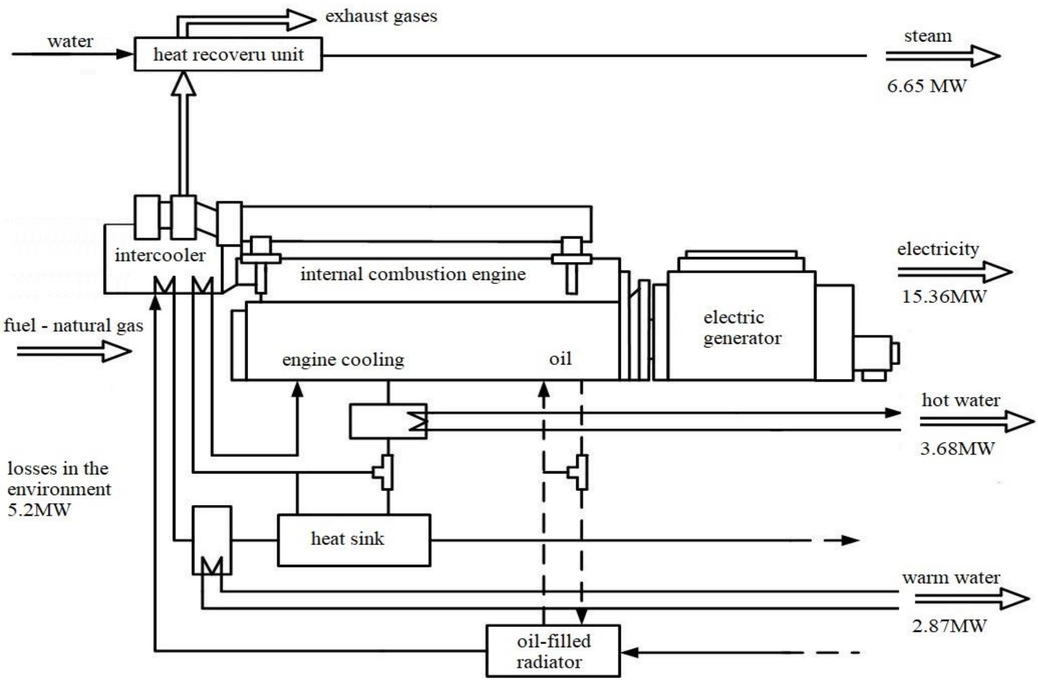

Fig. 5. Heat balance of a cogeneration unit

Rys. 5. Bilans cieplny jednostki kogeneracyjnej

When carrying out any analysis for the recovery of heat from primary piston engines, it is necessary to conduct an economic evaluation of the reorganization of the thermal scheme of the enterprise. Operating costs, costs related to ensuring the safety of operation of new equipment, and engine maintenance costs cannot be calculated as easily as costs related to fuel consumption, recovered heat, or initial costs. Total maintenance costs can be broken down into three main factors:

- miscellaneous and service maintenance costs;
- labor costs when carrying out basic and partial repairs of all parts during certain periods of time;
- labor costs when performing various types of service services.

The first two factors change significantly due to the precision with which the engines must be serviced. The third factor is also expected to be variable regarding labor costs in relation to fast service. Because of the many variables, it is difficult to give real numbers that will be valid for all applications.

Based on the specific case considered and the fact that cogeneration plants based on an internal combustion engine produce electricity and heat in a ratio of 1:1.2, the savings from their implementation will cover all the costs of the system. It is expected that during the construction of such an installation, the return on capital investments for its construction will be for a period of two to five years.

Conclusion

From the presented load schedules for the annual electricity and steam consumption, the conclusion follows that the sizing of a cogeneration plant and its technical parameters will depend entirely on the amount of production.

Relatively constant heat load over time and its power allow for the inclusion of a co-generator in the enterprise's energy system. In addition, such a system will increase the efficiency of the heating scheme compared to the currently used natural gas-burning facilities.

As the present study is a preliminary energy analysis, economic benefits are expected, but with proper sizing and design of the installation. It is important to note that the economic benefits will increase the company's competitiveness and its employees' social benefits.

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Konstantin Vasilev Kostov

Bilans energetyczny i analiza możliwości wdrożenia kogeneracji w zakładzie tekstylnym

Streszczenie

Kogeneracja jest jedną z wiodących technologii. Z biegiem czasu została wprowadzona przez prawie wszystkie rozwinięte i aktywnie rozwijające się kraje na świecie. Jednak osiągnięcie wysokiej efektywności energetycznej przy inwestowaniu w taką produkcję nie jest absolutną regułą, ale kwestią dokładnej oceny technicznej i ekonomicznej istniejących warunków. Zarządy przedsiębiorstw tekstylnych zazwyczaj koncentrują się na poprawie wyników ekonomicznych i operacyjnych, ale pomimo korzyści płynących z kogeneracji, nie chcą podejmować ryzyka związanego z jej wdrożeniem, ponieważ wiąże się to z dużymi inwestycjami strategicznymi w sektorze. Przeprowadzenie badań mających na celu identyfikację i analizę specyficznych warunków funkcjonowania danego przedsiębiorstwa włókienniczego pozwoli na analizę możliwości wprowadzenia kogeneracji. Spojrzenie na strukturę zużycia dwóch rodzajów energii (ciepła i energii elektrycznej), dynamikę cen oraz położenie geograficzne są przesłankami do zbadania możliwości wprowadzenia wspólnej produkcji ciepła i energii elektrycznej w dużym przedsiębiorstwie włókienniczym. W artykule przeprowadzono analizę zużycia energii pierwotnej, sporządzono bilans cieplny rozpatrywanego przedsiębiorstwa oraz wyprowadzono obiektywne parametry ekonomiczne i techniczne oparte na charakterystyce technologii. Na podstawie analizy uzyskanych wyników wyciągnięto wnioski dotyczące możliwości wdrożenia wspólnego pozyskiwania ciepła i energii elektrycznej w przedsiębiorstwach tekstylnych. Wykazano nowatorskie podejście naukowe poprzez zastosowanie nowego podejścia do kompletnego rozwiązania, mającego na celu osiągnięcie czystszej produkcji i zwiększenie efektywności energetycznej rozważanego przedsiębiorstwa tekstylnego.

Słowa kluczowe: kogeneracja, zakłady włókiennicze, bilans energetyczny, struktura zużycia energii