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DETERMINE THE OPTIMAL SYSTEM STRUCTURE OF THE COMBINED PRODUCTION OF ELECTRICITY AND HEAT

WYZNACZANIE OPTYMALNEJ STRUKTURY SYSTEMU KOGENERACJI CIEPŁA I ELEKTRYCZNOŚCI

A b s t r a c t

For most of the EU, final energy is consumed in buildings as low-temperature heat for space heating and hot water. This is mostly produced by burning fuels that are linked to adequate environmental load environment, regardless of whether it is a fossil or bio-fuel. It is therefore high efficiency fuel which is a natural requirement in designing, implementation and operation of heat sources for the supply of buildings. For this reason, before commonly used conventional mono-production of heat a more efficient technology should be preferred, combining heat and power. This technology is, however, much more difficult as far as investments are concerned. Accordingly, its share in total production of heat needs to be set so that the operation of the heat source was also economy effective. This paper presents a simple method to solve this problem.

Keywords: *biomass*, *renewable energy sources*, *cogeneration*

S t r e s z c z e n i e

W większości krajów Unii Europejskiej energia końcowa jest używana w formie ciepła niskotemperaturowego do ogrzewania i ciepłej wody użytkowej. Jest ono głównie wytwarzane przez spalanie paliwa, co związane jest z obciążeniem środowiska, niezależnie od tego, czy jest to paliwo kopalne czy biopaliwo. Potrzebne jest zatem wysoko wydajne paliwo, jako oczywisty wymóg w zakresie projektowania, realizacji i eksploatacji źródeł ciepła dla budynków. Z tego powodu, zamiast powszechnie stosowanych konwencjonalnych monoźródeł wytwarzania energii cieplnej należy preferować bardziej efektywne techniki łącznego wytwarzania ciepła i energii elektrycznej. Ta technologia jest jednak znacznie trudniejsza, w szczególności ze względów inwestycyjnych. W związku z powyższym jej udział w całkowitej produkcji ciepła musi być ustawiony tak, żeby działanie takiego źródła ciepła było również efektywne ekonomicznie. W artykule przedstawiono prostą metodę rozwiązania tego problemu.

Słowa kluczowe: *biomasa*, *odnawialne źródła energii*, *kogeneracja*

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1. Introduction

In the EU the proportion of the energy supply in buildings is the biggest with 45% (Fig. 1). The energy demand of buildings means the use of end-energy in the complex system of energy supply. The electrical energy demand of lighting, household appliances etc. can be often neglected compared to the summarised yearly heat demand of heating and DHW supply and of the HVAC, but in households or in exceptional cases, like in shopping centres, this proportion can be inverted.

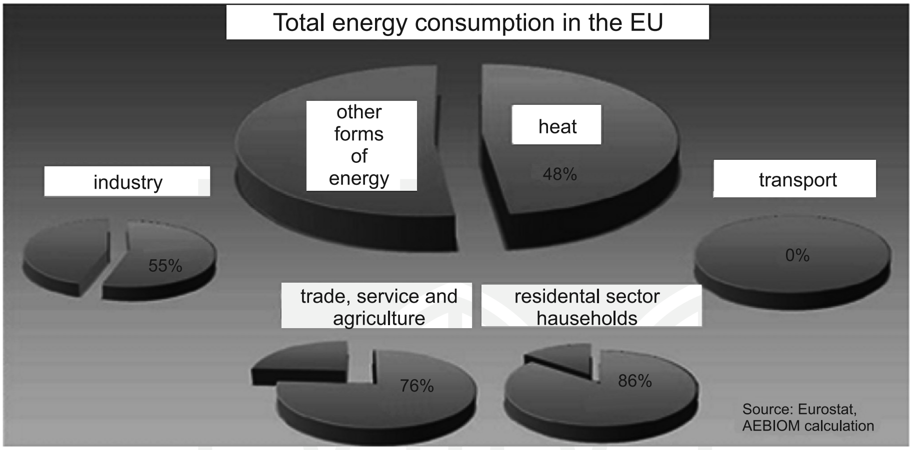

Fig. 1. Proportion of energy consumption of building

Figure 1. shows that the heat supply in residential buildings, like the heat demand of the heating and DHW is more than 80%. This heat demand can be covered from low temperature heat sources (renewable energies, waste heat). In Slovakia the most expensive fossil energy (natural gas) is used in ca. 70% with low effective direct heat production. This fact is even more worrying because in Slovakia almost 100% of natural gas demand is covered by importing from Russia. The last Russian-Ukraine gas conflict caused a big drop in Slovakian industrial production and this shows that high import dependency presents a reasonable risk parameter for a national economy.

Energy and environmental viability of production of electricity and heat in cogeneration production in condensing power sources compared with separate and conventional heat sources is beyond doubt. To ensure the competitiveness of this technology is, however, crucial to higher economic efficiency. In the area of decentralized heat-supply systems this is, difficult to achieve. Specific investment costs are substantially higher than for cogeneration technologies for conventional heat sources. The incorrect choice of the parameters of the source, e.g. the cogeneration. The resizing, therefore has a much less favourable impact on economic results, rather than in the case of conventional heat sources.

Therefore, it is necessary in the preparation of projects to analyse and take into account all the factors of cogeneration sources which are particularly sensitive, the resulting effect in a positive or negative sense. Conceptual weaknesses of the project of a particular system as well as the weaknesses of the technical performance of its individual components and incorrect conception of operation may spoil the "image" of this very progressive energy technology.

2. Distribution of the peak power source of cogeneration

According to cybernetic model of cogeneration source is generally made up of cogeneration and conventional subsystems. Cogeneration of heat and electricity generated in the production of storage subsystems. It consists of one or more according to the size of cogeneration units. Conventional systems produce heat output only, which is also often divided into two, or even more boilers.

The resulting economic efficiency crucially depends on the peak distribution source of the cogeneration of heat and power necessary for the supply of cogeneration systems on conventional consumers and subsystems. The use of cogeneration units of smaller performance allow flexibility of the heat output to adapt the total piston gas engines or micro--turbine to the requirements of consumers. Determination of thermal performance of cogeneration in the subsystem often solves the problem as the number of election of cogeneration units. In the manufacture of the same quantity of heat (cogeneration production of heat) while saving primary energy by any unit causes, compared with mono-production heat, but by far not certain that this is sufficient to compensate for higher investment in more sophisticated systems. From the perspective of competitiveness of cogeneration it is necessary that such distribution of peak power sources, where high energy efficiency is achieved at the maximum economic efficiency. The target function can be the maximum value of profits caused by cogeneration production. Condition may be the choice of a number of smaller cogeneration units at which the unit with the smallest annual gain.

In the elaboration of the methodology, we relied on the results of the energy and economic analysis of the combined production of heat and electricity published in (1).

The most important result of the energy analysis is the expression of the primary energy savings related to the heat Q_{KJ} produced by the cogeneration unit.

$$\alpha_{Q,KJ} = \frac{G_U}{Q_{KJ}} \tag{1}$$

where:

G_U – the saving of primary energy caused by the operation of a cogeneration unit.

From energy analysis: primary energy savings on the quantity of heat produced by the cogeneration subsystem.

$$\alpha_{Q,KJ} = \sigma_{KJ}\left(\frac{1}{\eta_{KE}} - \frac{1}{\eta_{G,KJ}}\right) \tag{2}$$

where:

$\sigma_{KJ} = \dfrac{E_{KJ}}{Q_{KJ}}$ – modul of electricity production,

η_{KE} – efficiency of electricity production,

$\eta_{G,KJ} = \dfrac{E_{KJ} + Q_{KJ}}{G_{KJ}}$ – total efficiency of the cogeneration unit.

Saving primary energy caused by the cogeneration unit can be expressed by:

$$G_U = Q_{KJ}\alpha_{G,KJ} \text{ [MWh/year]} \tag{3}$$

The most valuable result of economic analysis is the expression of specific cost savings to the heat produced by the cogeneration unit:

$$k_{G,U,KJ} = \frac{C_U}{Q_{KJ}} \tag{4}$$

$$k_{G,U,KJ} = \sigma_{KJ}\left(k_{KE} - \frac{P_{G,KJ}}{\eta_{G,KJ}}\right) [\neg / \text{MWh}] \tag{5}$$

where:

k_{KE} – the cost of separate production of electricity [€/MWh].

Cost saving can be expressed by relationship:

$$C_U = Q_{KJ} \cdot k_{Q,U,KJ} \text{ [}\neg\text{/year]} \tag{6}$$

Cost saving allows you to express the profit due to a cogeneration unit:

$$\Delta Z = C_U - \alpha\Delta B \text{ [}\neg\text{/rok]} \tag{7}$$

where:

$\Delta B = Q_{KJ} \cdot \Delta b$ – the excess of investment costs,

Δb [€/GJ] – specific investment costs and a is annual annuity.

Previous relations allow us to express gain related to surplus investment cost $\Delta Z/\Delta B$. The relations can be used to determine the optimal proportion of heat and power in a cogeneration subsystem. In particular cases, they can often be used as to determine the optimal number of cogeneration units in which the maximum gain for smaller performances is obtained.

3. Application of the methodology for determining the optimal heat-power cogeneration subsystem

We have applied the methodology for determining the optimal number of cogeneration units to the case in which the source designed for cogeneration was one KJ with microturbine (IR Energy Systems 70LM), with an electric power of 70 kW, and a heat output of 108 kW for the annual preparation of the determination of the optimal number of cogeneration units. Such a proposal may cause primary energy savings, while the simplified and costs and ultimately profit, but from the optimal alternatives may be quite far away.

Theoretically in this case it would be possible to operate 6 such cogeneration units with annual use as in Fig. 2. By means of input data specified by table 1 we have received the above relations results, which are summarised in Table 2 for the autonomous operation of the individual cogeneration unit, and in Table 3 for the operation of the current cogeneration unit.

Table 1

Assessment of energy performance

INPUT DATA			
Heat output of the cogeneration unit	Q_{KJ}	0.108	[MW]
Electric power cogeneration unit	P_{KJ}	0.07	[MW]
Modul of heat plant production	Θ_{KJ}	0.65	
The overall efficiency of the cogeneration unit	$\eta_{G,KJ}$	0.6	
Efficiency of separate heat production	η_{K}	0.85	
Efficiency of separate electricity production	η_{KE}	0.37	
Specific costs of separate production of electricity	K_{KE}	82	[€/MWh]
Overlap specific investment costs	Δb_{KJ}	750000	[€/MWh]
Average annual annuity	a	0.16	[1/year]
Price of fuel in the source	p_{G}	21.6	[€/MWh]

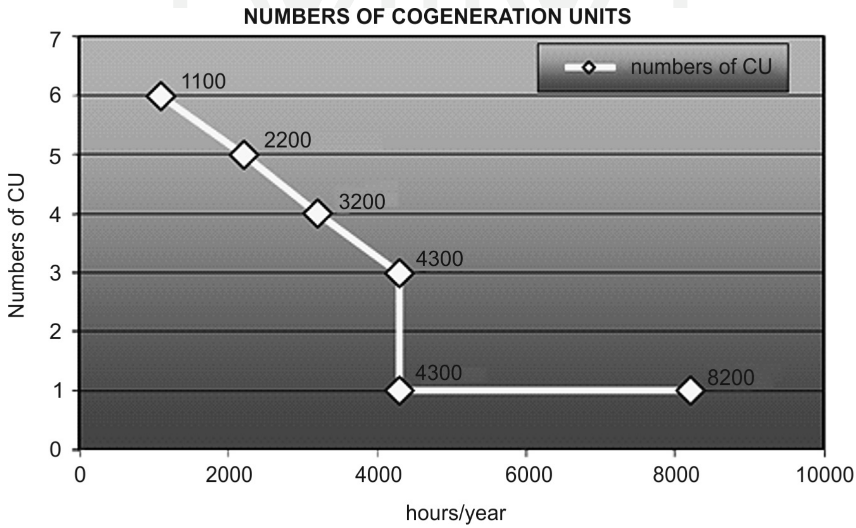

Fig. 2. Technically adequate structure of the cogeneration subsystem

The number of cogeneration units is determined from the condition that in the last one cogeneration unit must be involved in generating profit. After determining the number of cogeneration units, we can take stock of the impact of increasing the number of cogeneration units to save energy, costs and profit. Based on the input data which was evaluated by software, the numerical values of the parameters and their graphical representation.

Table 2

Parameter of the autonomous service of individual cogeneration unit

Number		Q_{KJ}	G_U	C_U	ΔZ	ΔB	$\Delta Z/\Delta B$
CU	[h/year]	[MWh/year]	[MWh/year]	[€/year]	[€/year]	[€]	[%/year]
1	8200	885,6	594.685	26404.000	18004.000	52500	34.293
1–2	6250	1350.000	906.532	40250.000	23450.000	105000	22.333
1–3	5600	1814.400	1218.378	54096.258	28896.258	157500	18.347
1–4	5000	2160.000	1450,450	64399.098	30799.098	210000	14.666
1–5	4440	2397.600	1610.000	71483.292	29483.292	262500	11.232
1–6	3883.333	2516.400	1689.775	75024.068	24624.068	315000	7.817

Table 3

Parameter of the autonomous service of individual cogeneration unit

	τ	Q_{KJ}	G_U	C_U	ΔZ	ΔB	$\Delta Z/\Delta B$
CU	[h/year]	[MWh/year]	[MWh/year]	[€/year]	[€/year]	[€]	[%/year]
1	8200	885.6	594.685	26404.000	18004.000	52500	34,293
2	4300	464.400	311.847	13846.000	5446.000	52500	10,373
3	4300	464.400	311.847	13846.258	5446.258	52500	10,374
4	3200	345.600	232.072	10302.841	1902.841	52500	3,624
5	2200	237.600	159.550	7084.193	–1315.807	52500	–2.506
6	1100	118.800	79.775	3540.776	–4859.224	52500	–9.256

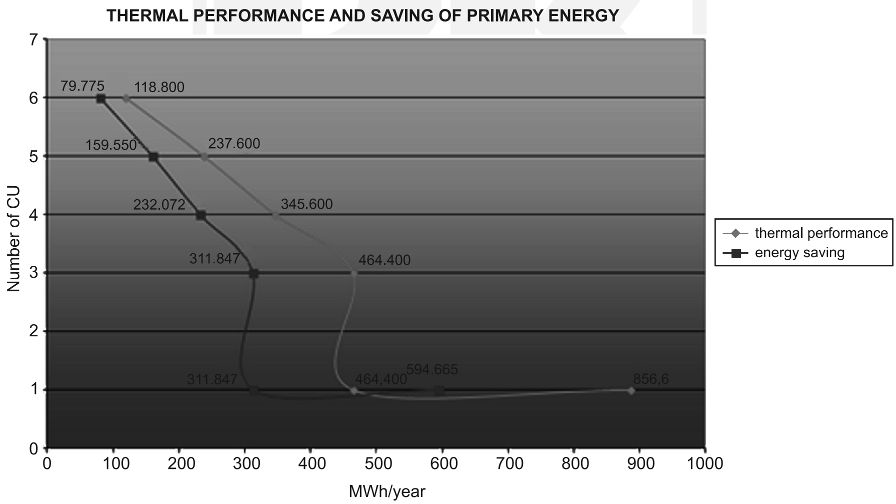

Fig. 3. Thermal performance and saving of primary energy

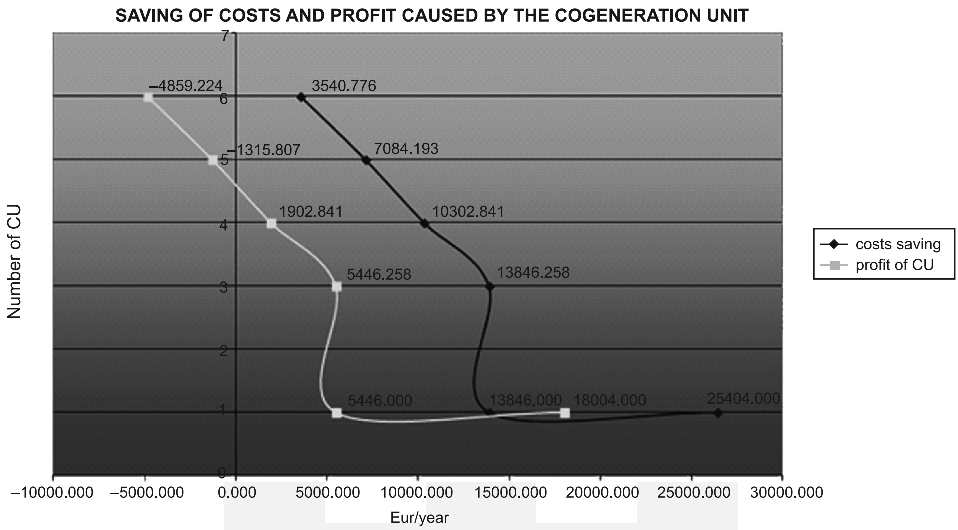

Fig. 4. Saving of costs and profit caused by the cogeneration unit

The number of cogeneration units is determined from the conditions that, in order to produce profit for the latest cogeneration unit shall $\Delta Z_n > 0$. It follows that the optimal number of cogeneration units in this case would be $n = 4$, which should reach almost twice the profit compared with the original proposal with one cogeneration unit.

4. Conclusions

In professional circles it is considered that when designing cogeneration subsystems of electricity need, in the current economic environment it is necessary to achieve the desired economic efficiency. Thermal performance of cogeneration and, consequently, also the share of annual consumption of cogeneration heat tends to be relatively small. However, the point of view of energy efficiency and the environment tends to be less favourable than the design of the heat needed as necessary.

The original philosophy of cogeneration is based on an effort to utilize waste heat released when electricity is produced. However, the concept is based on an effort to produce electricity more effectively in cases when it is necessary to produce a relatively large amount of heat. It follows that cogeneration source should be scaled according to the heat needed, but with a certain compromise as to the share of the thermal performance of cogeneration in the overall heat performance of the source. Increasing fuel prices used in the cogeneration sources and electricity energy pushes this proportion to be higher.

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References

[1] Buki G., *Kapcsolt energiatermelés*, Műegyetemi Kiadó, Budapest 2007.

[2] Dvorský E., Hejtmánková P., *Kombinovaná výroba elektrické a tepelné energie*, Vydavateľstvo Technická literatúra BEN, Praha 2005.

[3] Faninger G., *Thermal Energy Storage*, IEA SHC Task 28, Subtask 28.2.4 (www.iea.shc.org).

[4] Böszörményi L., Böszörményi G., *The Barriers and Possibilities of Heat Supply Sustainibility*, [In:] ASHREA Transaction, Volume 114, Part 2.

[5] Eurostat, AEBIOM calculation (www.enef.eu).