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Značaj sistema daljinskog grejanja u periodima energetske krize: Studija slučaja za grad Skoplje

The importance of district heating systems in periods of energy crisis: Case study for the city of Skopje

Igor Shesho, Monika Uler-Zefikj, Risto Filkoski, Done Tashevski

Faculty of Mechanical Engineering, University "Ss Cyril and Methodius" in Skopje, Republic of North Macedonia

Rezime - Današnje energetske krize karakteriše njihov intenzitet, odnosno one za kratko vreme mogu izazvati značajne posledice na privredu i život u celini. Uticaji energetske krize se uglavnom ogledaju indirektno kroz neravnotežu u proizvodnji električne energije, koja je glavna komponenta i temelj svih društveno-ekonomskih procesa. Pored toga, trenutna koincidencija energetske krize (visoke cene prirodnog gasa) sa grejnom sezonom otkriva i naglašava značaj energije za grejanje. Cilj ovog rada je da analizira ulogu, prednosti i nedostatke postojećih sistema daljinskog grejanja sa kogeneracionim elektranama (CHP), kao važne karike u elektroenergetskom sistemu zemlje, posebno u vremenima energetskih kriza. U analizama se kao referentni sistem razmatra sistem daljinskog grejanja u Skoplju, Republika Severna Makedonija. Ocena uticaja na fluktuacija u potrošnji toplote u sistemu daljinskog grejanja na elektroenergetski sistem, vrši se korišćenjem simulacionog softvera za energetsko modeliranje sistema daljinskog grejanja u Skoplju, u vezi sa podacima za godišnju (časovnu) potrošnju električne energije. Dodatna ekonomska procena se sprovodi kako bi se utvrdila troškovna konkurentnost sistema daljinskog grejanja sa drugim individualnim tehnologijama grejanja koje su dostupne u urbanim sredinama. Rezultati pokazuju da su sistemi daljinskog grejanja sa kogeneracijskim elektranama u gusto naseljenim urbanim sredinama troškovno optimalan sistem grejanja i izuzetno važna karika u energetskom lancu zemlje, koja obezbeđuje energetsku stabilnost, uz potencijalne posledice u slučaju dužih (ne)predviđenih prekida rada.

Ključne reči - energetske krize, sistemi daljinskog grejanja, simulacija, kogeneracijske elektrane

Abstract - Nowadays energy crises are characterized by their intensity, i.e. for a short period of time they can cause significant consequences on the economy and overall living. The impacts of energy crisis are mainly reflected indirectly through misbalance in electrical energy production, which is main component and foundation for all socio-economic processes. In addition, the current coincidence of the energy crisis (high price of natural gas) with the heating season reveals and emphasizes the importance of the heating energy. The aim of this paper is to analyse the role, advantages and disadvantages of existing district heating (DH) systems with cogeneration power plants (CHP), as an important link in the country power system, especially in times of energy crises. In the analyses as a reference system is considered the DH system in Skopje, Republic of North Macedonia. Assessment for the influence of the fluctuation in heat consumption in the DH system on the power system is performed by using simulation software for energy modelling of the district heating system in Skopje, linked with the data for yearly (hourly basis) electricity consumption. Additional economic assessment is conducted to determine cost competitiveness of DH system with other individual heating technologies available in urban areas. Results reveal that district heating systems with cogeneration power plants in densely populated urban areas are cost optimal heating system and extremely important link in country energy chain, providing energy stability, along with potential consequences in case of longer (un) foreseen interruptions in operation.

Index Terms - Energy crises, District heating systems, Simulation, Cogeneration power plants

I Introduction

The system for district heat distribution and transmission represents capital good for the society providing consumers with heating energy leading to general comfort and satisfaction [1]. According to Eurostat, residential space and water heating together account for more than 80% of the final energy consumption in EU countries [2]. Heat Roadmap Europe projected that until 2050 half of the heating energy will be supplied by DH systems [3].

DH systems provide heat and hot water generated centrally by CHP to the consumers through a network of pipelines. Working in combined heat and power mode, a CHP plant may have a total efficiency of 85-90% resulting in an overall fuel saving of approximately 30%, compared to separate production of heat and electricity [4]. CHP coupled with DH systems had 98% balancing capacity on the power sector in 2020 and are estimated to have 84% in 2050 [4]. Also, heat produced in larger power plants, such as CHP is cheaper than in individual source [5]. For achieving additional decarbonization of the EU system the plan is to replace coal with biomass as the main fuel in the CHP plant until 2025 [4].

Compared to individual heating solutions, DH systems can use different types of fuels not being limited to one specific type, thereby taking advantage of the free price market. This leads to flexibility of DH production which is additionally increased by coupling DH systems with CHP and thermal storage [4, 6]. Additional advantages compared to the traditional heating systems are energy savings, implementation of control and regulation systems, and improved troubleshooting. DH systems have the potential to develop into smart DH systems and become an integral part of smart energy systems and energy grids [7]. According to the results from the assessment done by Famiglietti et al., DH systems will contribute to a 19% reduction of CO2 emissions in the future [8]. The widespread use of district heating and combined heat and power is one of the main reasons why it has been possible to increase energy efficiency and reduce carbon emissions over the past decades.

The International Energy Agency estimated that the renewable energy systems (RES) input in DH sector will increase until 2025 up to 14%. Implementing seasonal storage will increase the share of renewable energy in DH systems [3]. Increasing energy efficiency and sustainability of DH systems can be achieved by implementing and maximizing the share of renewable energy sources in the system contributing to the reduction of GHG emitted [9]. There are numerous benefits from the use of renewable energy sources in the DH systems divided into several categories: environmental and systematic benefits, benefits related to energy security, and synergy with the urban environment. The environmental advantages are related to lowering CO2 emissions leading to decreased urban air pollution thus reducing health costs, as well as setting clean energy targets. The systematic benefits refer to the correlation of DH systems with the electric and economy sector leading to cross-sectorial benefits which support the electric system, demand regulation, storage availability. By increasing energy security of DH systems, energy independence and diversification are achieved, as well as price stability [10].

In this paper three different scenarios will be analyzed regarding redistribution of heat consumption to different systems and sources of heat in case of long-term interruption in the operation of the DH system. As reference DH system is taken the system of the city of Skopje, R. Macedonia which will be described later in part II Background analysis. In order to assess the influence of the fluctuation in heat consumption in the DH system on the power system simulation software was used. Data about the software, as well as details about the input parameters are given in section III Materials and methods. Part IV Results and discussion gives additional economic assessment for determining the cost competitiveness of DH system with other individual heating technologies available in urban areas, together with the results from the simulation software.

II Background analysis

At the end of 2021, as a result of several factors, an energy crisis begins, which is essentially a financial crisis, because there is enough energy but at a high price. The fact that the beginning coincides with the beginning of the heating season implies an additional intensity to this crisis, which raises a series of questions about the potential risks and dangers that lie ahead. The issue of thermal energy users connected to the heating system is especially raised. A series of activities are being undertaken in order to amortize the price shocks from the increase of energy prices. In addition to the analysis of changes in the price of electricity, emphasis is placed on increases in heat prices for users of the heating system operated by Balkan Energy Group (BEG), as a system that serves a relatively large number of heat consumers.

The DH system of Skopje covers around 40% of the total heating needs of the city using distribution network in length of 200 km containing 2700 heating substations [11]. It is composed of three independent heating systems operated by BEG, ESM Energetika and Toplifikacija Skopje North. The heat supplying the DH system is generated by three heating plants and one CHP. The heating plants work on natural gas as primary fuel and fuel oil as reserve fuel in case of lack of natural gas. Heating plant „Toplana Istok“ is located in the eastern industrial zone of the city with hot water capacity installed of 279.12 MW. Heating plant „Toplana Zapad” is placed in the western part of the city having installed heating capacity of 162.82 MW. Heating plant „11 Oktomvri” is preserved since 2015 but can supply 28.25 MW of hot water capacity. In total, the three heating plants provide heating capacity of 470.19 MW. Additional heating and electricity are provided by the CHP „TE-TO“ AD Skopje working with combined cycle gas turbine (CCGT). It has 160 MW installed heat thermal capacity for district heating and 220 MW electrical power.

In the DH system, there are two distribution pipelines creating connection between the two heating plants. Pipeline A connects heating plant „Toplana Istok” with Kozle pipeling from heating plant „Toplana Zapad”. Pipeline B connects heating plant „Toplana Istok” to the pipeline „Partizanska“ from heating plant „Toplana Zapad” [12].

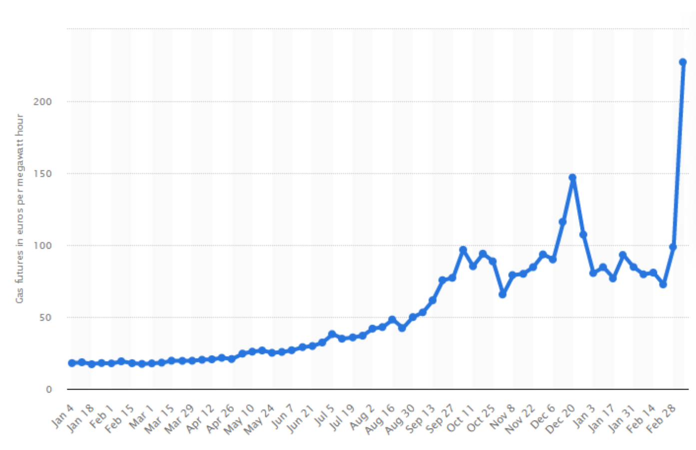

Figure 1. Natural gas price trend from January 2021 - February 2022 [13]

The Regulatory Commission of Macedonia and the government have analyzed several possible solutions to mitigate the consequences of the crisis. Last until the moment of the analysis for this paper, as a decision of ERC, it was made that BEG recognizes the increase of the price of heat to be 14%, starting from January 2022, and the state to buy the electricity from the combined thermal power plant "TE -TO ”AD Skopje at a price of

170 EUR/MWh. In the analyzed period when making these decisions, the price of natural gas is around 900 EUR/m_n^3, price trend presented in Figure 1. However, after the indication of the company BEG that with the increase of 14% it will not be able to operate profitably, the state, i.e the company owned by the state ESM will take over the operation and will subsidize and supplement the differences in the price of thermal energy.

The state subsidizing the price of thermal energy for the DH system in Skopje aims to amortize the dissatisfaction of the heat consumers, but also another important reason is to prevent the potential disconnection from the system in times of panic which can cause a domino effect and significant load on the power system. Hence the main motive for this paper is to quantify the potential load on the power system through the analysis of several scenarios. In addition, the LCOH methodology is used to compare the price of heat energy from the heating system with other potential (individual) devices and heat sources.

III Materials and methods

For the needs of the analysis of potential scenarios, the simulation software EnergyPLAN - Advanced analysis of smart energy systems was used [14]. The software is developed for study and research in the design of future sustainable energy solutions. With EnergyPLAN, the user can take a holistic approach focusing on the analysis of cross-sectorial interaction. Traditionally disparate demand sectors, such as buildings, industry, and transport, are linked to supply technologies through electricity, gas, district heating, and cooling grids.

The input data in the energy modeling of the DH system are defined with the: total heat consumption, heat losses in the pipeline network and hourly normalized data on heat consumption. The total delivered thermal energy on the threshold of consumers is on average about 450,000 MWh/year, while the maximum active/ engaged power is about 480 MW. The following Figure 2 shows the monthly heat consumption for 2018.

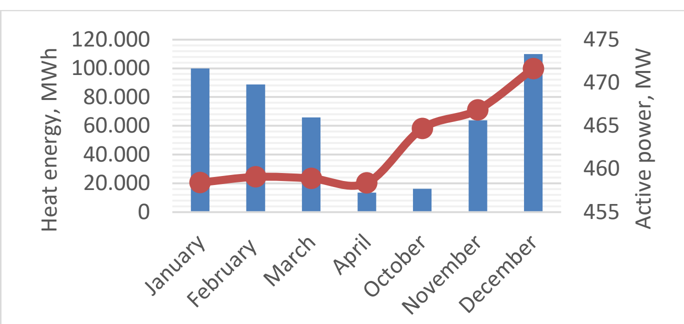

Figure 2. Monthly distributed heat energy on consumer threshold

Based on the available data on heat consumption, the average specific heat consumption depending on the purpose of the building is in the range of 100-140 kWh/m^{2}a, while the specific installed heat power is in the range of 100-140 W/m^2.

In case of long-term interruption in the operation of the DH system, three scenarios are analyzed, for the possible redistribution of heat consumption to different systems and sources of heat. Scenario 1 analyzes the most unfavorable energy situation, a case when all of the heat consume would migrate to direct utilization of electricity, with electric heaters and electric hot water boilers. In Scenario 2 it is adopted that 30% of the heat consumption will be heated by air-to-air heat pumps (air conditioners) with an average coefficient of performance of 2.7, while the rest will use direct electricity. Scenario 3 analyzes a case when 10% of the heat consumption is heated on biomass (wood) with an average efficiency of 80% of the devices, and 30% of the heat consumption with air-to-air heat pumps (air conditioners) and the rest directly on electric energy (electric heaters, electric hot water boilers).

IV Results and discussion

The three scenarios are dominated by individual heating systems with direct utilization of electricity because in general from a technical and economic point of view is practically the most acceptable way in terms of investment and construction. For each of the defined scenarios, an energy model is created in EnergyPLAN, where as basic data are entered the individual heat consumption and the normalized hourly data for heat consumption. Based on this data, a series of data can be read from the software, of which primarily important for this analysis is the electrical power that will burden the electrical power system. On Figure 3, Figure 4 and Figure 5 are presented average values for the required electric power, as well as hourly values for the required electric power.

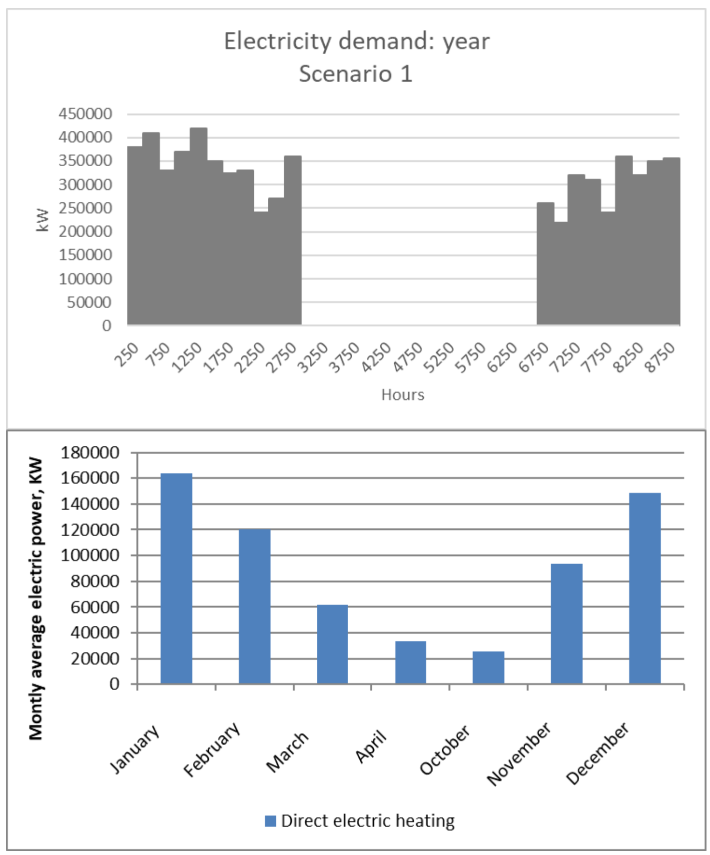

Figure 3. Scenario 1 - Distribution of average monthly and annual hourly electric power from the heat consumers

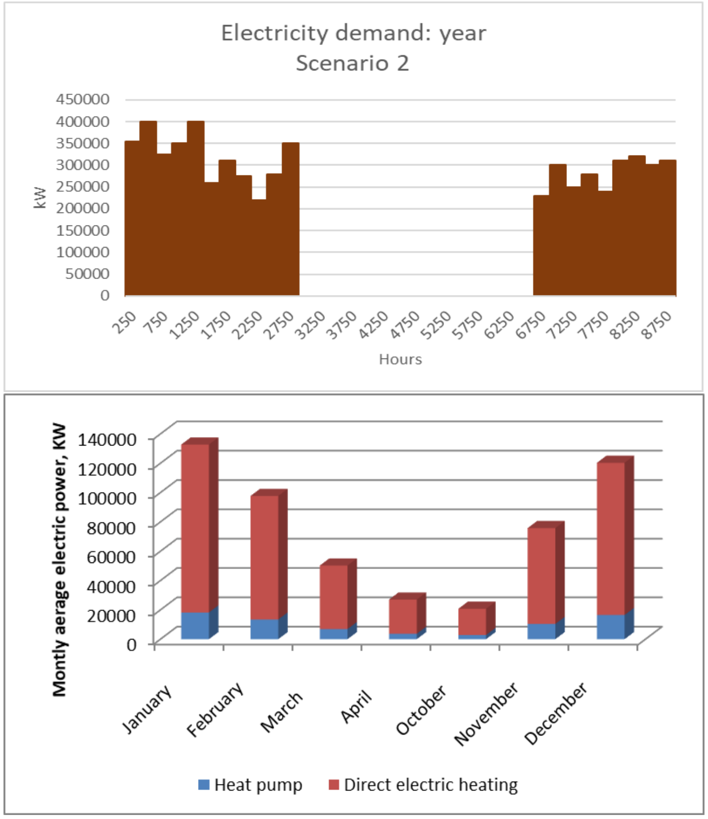

Figure 4. Scenario 2 - Distribution of average monthly and annual hourly electric power from the heat consumers

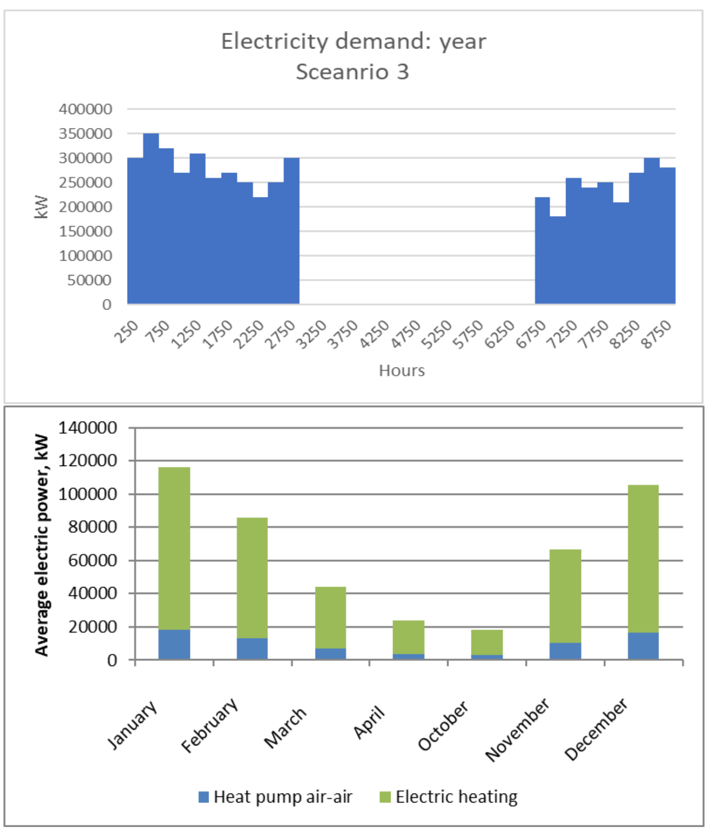

Figure 5. Scenario 3 - Distribution of average monthly and annual hourly electric power from the heat consumers

According to the presented results, it can be noticed that the peak electric power would be in the range of 350 - 450 MW depending on the scenario. This additional electrical power is a serious burden for the transmission of the low-power city power grid and obviously brings into question the overall stability and functionality of the network.

Therefore, in urban areas where there is an existing heating system, such potential dangers should be taken into account and responded to in a timely manner. In order to avoid the potential mass disconnection from the heating system, it is necessary to provide a competitive price of the heat energy from the district heating systems in relation to the individual heating systems. Therefore, a calculation has been performed to determine the Levelised Cost of Heat (Energy) (LCOH) for several heat technologies.

LCOH could be used to compare the cost of energy generated by a renewable resource with that of a standard fossil-fueled generating unit. This method is widespread in comparing different energy generation technologies. It considers comparison of the total costs (fixed + variable) in reference to an energy supply system with the energy supplied by this system over its lifetime.

LCOH is used as technical and economical Key Performance Indicator (KPI) in this paper to define the optimal system configuration.

Levelised Cost of (Heat) Energy is:

$$C_R = \frac{i(1+i)^n}{(1+i)^n - 1} \tag{1}$$

$$LCOE = \frac{C_R C_O + C_j}{E} \tag{2}$$

Where:

C_j - total annual costs, [euro/year]

C_o - investment costs, [euro/year]

C_R - capital recovery factor, [euro]

n - project lifetime, [years]

i - discount rate

E - produced energy (heat and electricity), [kWh/year]

Since multifamily residential buildings are dominant heat consumers of the DH system, for the calculations for LCOH it is considered reference apartment with an area of 70 m^2. The investment costs and heat source (energy) prices are presented in Table 1.

In Table 1, the investment cost refers only to the costs for the heat source technology and for the heat emitters it is assumed that are radiators. It should be noted that the obtained results for LCOH for each of the analyzed technologies are presented on Figure 6.

According to the results, it can be concluded that with the current market prices for the energy and investment for the analyzed technologies, the DH system has lowest LCOH.

It should be emphasized that the main contribution to the competitiveness of the heating system with the other analyzed systems is the participation of the cogeneration plant in the production of heat. However, it should be noted that for the analyzed period there are certain subsidies from the state, but certainly the subsidies in addition to heating energy from the heating system have subsidies in the price of electricity. In addition, CHP have a significant role in times of energy crisis because they efficiently enable the production of heat and electricity. The closest competitor in terms of LCOH of the heating system is the system with air-to-air heat pumps (air conditioners). Of course, air conditioners have the advantage of providing cooling, but still some analyzes indicate that the DH system in combination with air conditioners for cooling has again lower total costs. This is because in the case of air conditioners that are provided for heating, the heating capacity must meet the heat losses at the outside design temperature, which in turn predicts oversizing the air conditioners on the cooling capacity and correspondingly have higher investment costs, compared to being used for cooling only. The system with the highest value for LCOH is the electrical hot water boiler. However, in the analysis of potential alternatives to DH systems in case of predictable and unpredictable complete interruptions in the operation of the system, the electric boiler (or electric heaters with similar efficiency) are selected for analysis, since in financial and installation aspect are practically the most applicable for most users.

Table 1. Input parameters for LCOH calculation

Apartment area	70	m^2
Specific heat energy consumption	100	kWh/m^2a
Specific heat load	100	W/m^2
Variable energy price - DH	0,035	EUR/kWh
Fixed price - DH	20,9	EUR/KW
Specific DH price	0,06	EUR/kWh
Electricity price - high	0,126	EUR/kWh
Electricity price - low	0,064	EUR/kWh
Wood pellet (Hd = 4,5 kWh)	0,25	EUR/kg
Wood pellet (Hd = 4,5 kWh)	0,056	EUR/kWh
Heat pump air-water COP (seasonal)	3	
Heat pump air-air COP (seasonal)	2.7	
Investment cost		
District heating	500	EUR
Electric boiler	650	EUR
Heat pump air to air	2500	EUR
Heat pump air to water	4200	EUR
Wood pellet boiler	1050	EUR
Operation and maintenance	2% from investment	

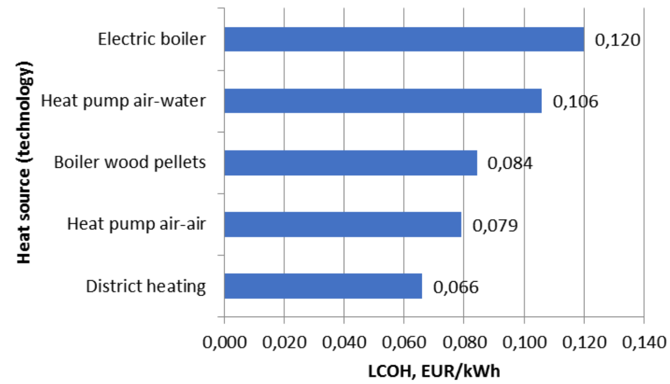

Figure 6. LCOH for the analysed heat technologies

V Conclusion

Analyzes have been made in order to determine the importance of DH systems with CHP in densely populated urban areas. The results indicate that DH systems with CHP are economically competitive in regard to heat energy prices compared to other available individual heating systems. Considering that DH has centralized heat production, it provides opportunity for relatively simple integration of RES in the production of heat and thus can significantly contribute toward decarbonization of the heating sector. DH systems have added value for densely populated urban areas since they also significantly contribute to the local reduction of air pollution and climate change. The results from the analysis indicate that in case of long-term interruptions of the DH system in Skopje, there could be relatively high burden on the electricity power network with peaks of 350 - 450 MW, which poses a serious threat to network stability. It can be concluded that DH systems in conjunction with cogeneration plants and renewable energy sources have potential for economic and environmental advantages over individual systems in densely populated urban areas.

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AUTORI/AUTHORS

Igor Shesho - Associate professor, Department of Thermal Engineering, Faculty of Mechanical Engineering Skopje igor.seso@mf.edu.mk

Monika Uler-Zefikj - Teaching assistant, Department of Thermal Engineering, Faculty of Mechanical Engineering Skopje monika.uler-zefikj@mf.edu.mk, ORCID 0000-0002-0421-1142

Risto Filkoski - Full professor, Department of Thermal Engineering, Faculty of Mechanical Engineering Skopje risto.filkoski@mf.edu.mk ORCID 0000-0002-3743-318X

Done Tashevski - Full professor, Department of Thermal Engineering, Faculty of Mechanical Engineering Skopje, done.tashevski@mf.edu.mk