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Article

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Reference: Nevlyudov, Igor/Ivanov, Leonid et. al. (2023). Justification of the need to modernize the existing central heating points in Ukraine. In: Technology audit and production reserves 6 (1/74), S. 41 - 46.
https://journals.uran.ua/tarp/article/download/293663/287372/679997.
doi:10.15587/2706-5448.2023.293663.

UDC 697.4
DOI: 10.15587/2706-5448.2023.293663

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JUSTIFICATION OF THE NEED TO MODERNIZE THE EXISTING CENTRAL HEATING POINTS IN UKRAINE

The object of the research is central heating points (CTP) in Ukraine. The problem that is being solved in the work is the need to modernize and automate existing CTPs. The importance of the problem is the presence of a large number of CTPs in Ukraine, which require urgent modernization of morally outdated equipment and automation of management of their work modes, which must be carried out in stages without removing them from operational status.

The need for modernization and further automation of the existing CTPs in Ukraine is substantiated, which is that this will allow increasing the efficiency of the CTPs through the use of modern technical equipment, software and trained specialists in the automated management of the process of heat supply to consumers. And it will also allow to reduce the cost of heat supply tariffs due to the reduction of non-production costs and to reduce the number of service personnel who manage work modes in manual mode. During the martial law, the timely resolution of problems with high-quality heat supply of the population acquires special importance.

The result of the conducted research is a theoretical analysis of the quality work of CTPs in the EU countries, realization of their capabilities and prospects for further use in order to transfer their experience to Ukraine. A theoretical analysis of the number and modern technical equipment of CTPs in Ukraine at the present time was also conducted.

As a result of the research conducted on the existing CTPs in Ukraine, a survey of their technical condition was carried out, specific directions for the phased modernization and automation of their equipment were developed and proposed, and additional measures were taken regarding the thermal modernization of main pipelines and modern thermal insulation of buildings and structures.

The possibility of practical implementation – step-by-step modernization and automation of the CTP, increasing the technical and technological capabilities of the equipment and reducing the tariffs for heat and water supply for consumers.

Keywords: *central heating point, obsolete equipment, modernization, automation, water supply, heat energy, electricity, consumers.*

Received date: 04.11.2023
Accepted date: 19.12.2023
Published date: 21.12.2023

How to cite
Nevlyudov, I., Ivanov, L., Yanushkevich, D., Hutsa, O., Opryshko, Y. (2023). Justification of the need to modernize the existing central heating points in Ukraine. Technology Audit and Production Reserves, 6 (1 (74)), 41–46. doi: https://doi.org/10.15587/2706-5448.2023.293663

1. Introduction

Today, centralized heat supply plays a very important role in providing heat energy to consumers in many countries of Europe, Asia, and America, because it is the most widespread form of combined production of heat and electricity [1–4].

The source of production of such combined energy is thermal power plants (CHPs), which allow savings in the production of primary fuel up to 40 %, a reduction in electricity consumption by 11 %, as well as a general saving of final energy consumption in the industry by 6 %. Therefore, CHPs, unlike other sources of energy production, are elements of the local market for the supply of thermal energy in limited areas.

According to expert estimates [5, 6], there are currently more than 80,000 such thermal energy markets in the world, of which:

– 50,000 are located on the territory of russia;
– 24,000 come from China, Ukraine, Belarus, Kazakhstan, the USA, etc.;
– 6,000 are located in the countries of the European Union.

According to experts from the American consulting company Global Market Insights, the global market for centralized heating in 2021 [7] was estimated at more than 150 billion USD. It is expected that the annual global consumption of thermal energy will exceed 14,000 PJ already in 2026.

Based on such data, experts predict that the district heating market will grow by 1.66 % during 2022–2026 [5, 8].

 ISSN 2664-9969

This is a world trend that is supported by the aggressive climate goals of the global economy and is based on estimates of the production indicators of heat supply enterprises, which are increasingly using modern high-tech equipment, which allows to raise energy production to a very high level.

As for the relevance and prospects of the development of centralized heat supply, along with the constantly evolving traditional types and forms of heat energy production, in the near future modernized markets of centralized heat supply will be integrated into a single energy supply system of all types of energy.

The aim of this paper is to investigate the need for a step-by-step modernization of the district heating system (DHS) in Ukraine. For this purpose, it is proposed to use automated means of managing CTP work modes to implement the tasks of increasing the real efficiency of their work in order to maintain quality living conditions of consumers.

2. Materials and Methods

District heating provides the supply of thermal energy in the form of hot water and steam from the CHP through a distributed network of pipelines with very high insulation to residential, industrial and commercial premises. The distribution between heat energy consumers directly depends on the heat load of these premises, industries and existing production processes. Therefore, the use of such an additional element as a heat point in the chain of centralized heat supply to consumers is a necessary condition.

The more powerful the technical potential of centralized heat points will be, the wider will be the application of centralized heat supply capabilities for consumer requirements (even industrial level).

Centralized heating (also called «heat networks» or «heat heating») is a system of centralized heat distribution that allows the production of coolant in a centralized place. The method of transporting the coolant is through well-insulated pipes to the place of consumption (to domestic and commercial consumers) in the form of heated water and space heating. The source of heat production is organic fuel.

The centralized heat supply system (Fig. 1) consists of:
- powerful central boiler (CHP);
- systems of well-insulated pipes, through which the coolant is, supplied both in the forward and reverse directions. As a rule, the pipes run parallel to the street or under it;
- CTP, with the help of its technical means (heat exchanger, water pumps, boiler) preparation and distribution of coolant to various heat consumers is carried out.

CTP capacity depends entirely on the degree of its automation and equipment.

The degree of automation completely depends on the performance of the following actions or modes of CTP operation:
- automated forecasting of heat loads based on customer data, operational data of technical equipment;
- automated planning of heat loads based on the weather forecast, data on calendar dates (number of working days, weekends and holidays).

These actions help to optimize and plan heat production, reduce heat consumption and avoid peak loads. Also, due to increased automation, the possibilities of using intelligent algorithms for searching and finding malfunctions in pipelines, such as detection of coolant leaks, replacement of inefficient/worn heating systems and errors related to the failure of technical means or elements of technical systems, are expanding.

Also, the analysis of literary sources showed that almost 60 million EU citizens receive heat precisely thanks to the centralized heat supply system, and another 140 million citizens live in cities where one or more centralized heat supply systems are located. According to statistical reports of the EU [5, 9–11], currently, with the help of central heat supply, about 11–12 % of the total demand of all heat consumers is met at the expense of 6,000 km of centralized heat supply networks.

Denmark has a great deal of experience and tradition in the use of centralized heat supply for the population and favorable conditions for its development using CHP. Yes, 80 % of the country's population lives in cities. The climatic conditions of the country require a very high annual consumption of thermal energy during the long heating season. Characteristically, all large CHP plants in Denmark are located in the immediate vicinity of these cities, so district heating is the most common source of heat there. CT systems exist in more than 450 cities.

Since the 90s of the 20th century, Denmark has achieved great success in the implementation of state energy programs, which allowed to increase the share of produced heat in centralized heat supply systems with a combined method of obtaining thermal and electrical energy from 33 % to 64 % [5, 8–11].

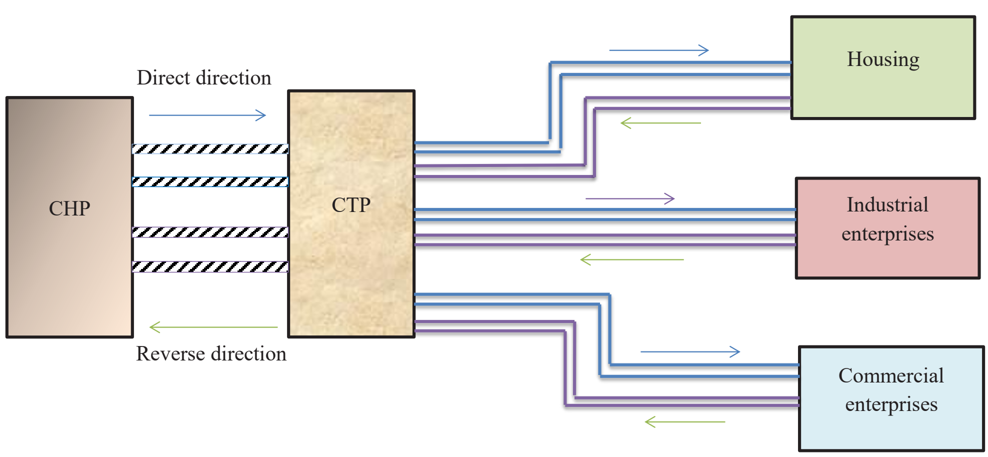

Fig. 1. Scheme of the centralized heat supply system

Centralized heating is also the main method of heating in Finnish cities. Today, the share of providing the country's population with heat due to centralized measures is 45 %, and in large cities it is more than 80 %. In the capital of Finland, Helsinki, the degree of centralized heating of the population is the highest in Western Europe and is at the level of 92 % of the total. Central heating systems are operated in more than 250 cities and towns of the country. At the same time, more than 70 % of the total heat is produced by thermal power plants. The total length of the country's central heat supply networks is about 8,000 km.

In Sweden, district heating accounts for 42 % of the total heat energy market, and in cities this share reaches 90 %, supplying mainly the municipal sector. The need for heat supply for the municipal and industrial sectors is 37 and 4 TW per year, respectively. Industrial consumers use the received thermal energy only for heating. Centralized heat supply systems are mainly under municipal supervision and are responsible for providing consumers with thermal and electrical energy. The total length of the country's CT is about 10,000 km. The share of heat supplied by the CHP is 25 % with the combined supply of thermal and electrical energy. In the capital of Sweden, Stockholm, the central heating system supplies the population with heat for about 60% of the total need for heating and hot water supply of the city [5, 8–11].

The system of centralized heat supply in Norway is 3 % of the total supply of heat energy to domestic consumers. The main source of energy for the production of heat supplied by the CT system is waste (49 %), another important source is oil (20 %) and thermal water, while the share of electricity is 11 %. In some regions of the country, connection to the CT system is mandatory. Currently, the total length of heat networks in Norway is 303 km. Oslo, the capital of Norway, is only 10 % supplied with heat from a centralized heat supply system. This feature of Norway's thermal power industry is connected with the share of hydropower, which reaches about 97 %.

Among the mentioned large European cities, such large cities as Berlin, Prague, Warsaw, Riga, Vilnius, Kaunas, Tallinn and others are equipped with sufficiently large systems of centralized heat supply.

Analysis of the development of central heat supply systems in European countries [5, 8–11] showed that the main direction of increasing the efficiency of heat supply to consumers in cities is the use of combined production of thermal and electrical energy, taking into account new technological methods during the reconstruction or construction of these systems. The use of modern technologies of production and heat transfer will allow several times to reduce the costs of operation and repair of equipment, as well as to reduce heat costs during transportation.

Maintaining relations between the manufacturer and all heat consumers will allow for a unified policy in matters of energy saving, efficient distribution of power from heat sources, connection of additional consumers, reduction of cases of irrational use of heat.

Increasing the efficiency in the operation of centralized heating points with the help of modern technologies should ensure a reliable and high-quality supply of thermal energy to all consumers.

The formation of centralized heat supply systems in Ukraine began in the second half of the 1930s in large cities, while the main systems in other cities were built in the 1950s and 1970s. In connection with the transition to gas heating, individual coal-fired boiler houses were closed, and they were replaced by district gas boiler houses and heating CHPs, which became the CT basis. The construction of centralized heat and hot water supply systems for homes ended in the early 1990s, when they switched from mass construction to individual construction. For almost 45 years, a very extensive infrastructure of the CT system was built in 420 cities of Ukraine [9, 11], which consisted of 28,000 boiler rooms, 42 CHPs and about 100,000 km of two-pipe CT.

After the collapse of the USSR, a lot has changed in Ukraine, namely: due to the rapid increase in the cost of organic fuel, the period of destruction of the central heating model, which was built in the 90s of the XX century, has come. A market economy came to Ukraine, which radically changed the relations between the state, municipalities, companies, CT and consumers. At the same time, the CT profitability decreased sharply, because the constant increase in fuel prices did not allow allocating funds for modernization and development. CT systems were operated without the necessary investments for about 60 years, so they became very old morally and physically. The wear and tear of heat networks negatively affected their general condition: cases of coolant leaks, burst pipes, accidents, and, as a result, non-receipt of heat supply services by consumers became more common. The technical condition of the heating station equipment has also deteriorated.

A separate negative impact on the state of centralized heat supply systems in Ukraine was exerted by the state tariff policy, which in many respects discredited the system of centralized heat and hot water supply and made many heating enterprises bankrupt [7, 12].

In order to obtain a complete picture of the negative transformation of central heating systems in the cities of Ukraine over the past 30 years, it is necessary to identify and consider the main negative changes that have occurred during this period, to assess the identified problems and threats in the industry in order to develop a further plan of specific actions aimed at modernization and development of the system as a whole.

3. Results and Discussion

The analysis of literary and statistical sources made it possible to identify the main negative changes in the field of centralized heat supply of Ukrainian cities that have occurred over the past 30 years. These include:

1. Mass refusal of industrial consumers from centralized heat supply services.

In connection with the rapid growth of energy prices, industrial enterprises of Ukraine were the first to refuse expensive CT services. Thus, during the period 1991–2010, the industry lost more than 20 % of thermal energy sales (compared to 1990) [7, 12].

The transfer of industrial heating power plants to communal or private ownership led to the mass construction of private boiler rooms (block-modular, roof-mounted, built-in/attached to the building, etc.). This led to a decrease in heat loads and a drop in the profitability of the CHP.

2. Reducing the demand for hot water from centralized sources.

The state policy, focused on the transition of consumers from centralized heating to electric and thermal energy, forced the majority of consumers to abandon centralized hot water supply in 25 years. The population began to massively install private electric boilers (apartment and home). Sales of hot water in the CT industry decreased by 70 %.

Also, during this period, the CT industry lost about 25 % of thermal energy sales, which led to the bankruptcy of CHPs in 420 cities of the country. Today, only 20 large cities of Ukraine have centralized hot water supply.

In Fig. 2, using the example of the city of Zaporizhzhia, Ukraine, the process of reducing the demand for the use of hot water for the period 2005–2023 is shown [11–13].

3. Construction of gas-fired boiler rooms at the sites of operating CHP plants.

In the initial period of operation of boiler plants, which worked on natural gas, and with the then low gas prices, the profitability of CTP operation was high, while the profitability of operation of thermal power plants, the source of which was coal, at the same time, fell sharply. Therefore, in the 90s of the XX century the strategy of local authorities (in order to reduce costs) was the gradual disconnection of CHP plants from consumers, their subsequent bankruptcy and closure due to unprofitability. Such a trend could be observed in such large cities of Ukraine as Kyiv, Kharkiv, Zaporizhzhia, Simferopol, Donetsk, Lviv, and others.

It should also be noted that in recent years, the tendency to use individual heating systems (autonomous boiler rooms) in new buildings has spread, which has led to the complete abandonment of CT in areas of modern buildings.

Thus, the conducted analysis of the use of centralized thermal energy in the cities of Ukraine showed that approximately 20 % of its sales, compared to 1990, have already been lost, and this process continues to spread. However, almost 80 % of consumers continue to use the services of centralized heat and water supply, the quality of which must meet the established standards [14].

A set of necessary measures for the timely solution of this problem is proposed. For this, it is necessary to carry out a step-by-step modernization of the entire heat supply system using modern materials and the application of modern technologies in the following directions:

Firstly, thermomodernization of the CT pipe economy due to the use of modern materials and methods of thermal insulation of pipes.

Secondly, modernization of the technical equipment of the CTP with further automation of their work modes. The experience of the EU countries shows that over 20 years of gradual modernization of the CT system, these measures will reduce the load on the system by approximately 8–10 times, reduce the costs of heat producers, which will make it possible to balance tariffs for the population, and improve the quality of services provided to consumers.

Thirdly, thermal modernization of buildings. Directive 2010/31/EU of the European Parliament and Council of May 19, 2010 on the energy performance of buildings [15], to which Ukraine has joined, defines directions for improving the energy performance of buildings within the EU, taking into account external climatic and local conditions, as well as requirements regarding the indoor microclimate and cost effectiveness.

Fig. 3 presents the directions of step-by-step modernization of the CT system in Ukraine.

The first stage of modernization concerns the main pipes that connect the CHP and CTP – their thermal insulation through the use of modern heat-saving materials along the entire distance. The materials that are most often used in the thermal insulation of pipes at the present time are mineral wool, expanded polystyrene and polyurethane foam. Based on the results of the study, it is proposed to use modern materials such as Al Plast – normaizol, among which foamed rubber and foamed polyethylene, as thermal insulation of main pipes.

In addition, simultaneously with the thermal insulation of pipes diverted from the CTP to the buildings and structures of consumers, it is proposed to install thermobarometric modern temperature and pressure sensors (marked with the letter «D» in Fig. 3) at a calculated distance from each other for automated control of these indicators in real time (with taking into account real climatic conditions).

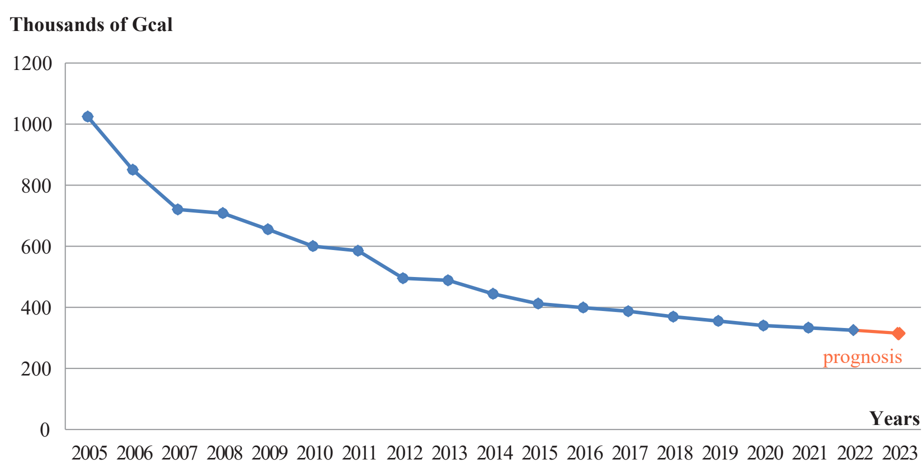

Fig. 2. Graph of falling demand for hot water supply (on the example of the city of Zaporizhzhia)

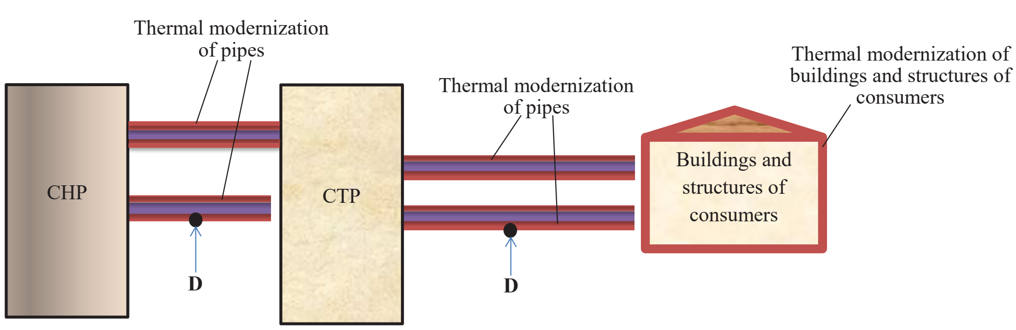

Fig. 3. Directions of step-by-step modernization of the CT system in Ukraine

The installation of temperature and pressure sensors on the pipeline will be carried out according to the results of the study, which was carried out regarding the measurements of these indicators at different distances, starting from the CHP, to the entrance to the CTP. Depending on the climatic temperature of the environment and the distance from the heat supply source (CHP boilers), the dependence of the drop in temperature and pressure of the heat carrier on the normative value was deduced. The dependence of a sharp drop in temperature and pressure indicators in the event of an emergency situation with subsequent determination of the location of the accident (leakage or rush) on the pipeline was also deduced. Thus, the correct installation of sensors on the pipeline will allow constant automatic control of temperature and pressure indicators and timely determination of emergency situations. Information from the sensors will be constantly sent to the dispatching center of the CTP. This will allow specialists to make timely decisions regarding the situation that develops on a real time scale on the pipeline. Such studies are already being conducted, their results will be presented in the following articles.

The second stage of modernization concerns the problem of gradual replacement of outdated technical equipment of the CTP: modern technical means with elements of computer technology and appropriate software to increase the degree of automation of technological process management should come to replace the outdated equipment at the CTP.

During the implementation of this stage of equipment modernization, it is planned not only to replace outdated equipment with new ones, but also to install additional new equipment, which is specially developed for this purpose. For this purpose, it is proposed to implement a set of additional technical means for the equipment of the heat exchanger of the CTP, namely: first, specialized intelligent temperature sensors for constant determination of the temperature of the heat carrier in the heat exchanger and the temperature of the environment. The need for this is due to sharp fluctuations in the ambient temperature in our area (frequent temperature crossings through climatic zero). The second is a programmable controller that will constantly receive information from temperature sensors, compare them and issue decision options for preparing the temperature of the coolant in the heat exchanger. The third is an electromagnetic valve, which should separate the supply of coolant with a sufficiently high heating temperature from the heat exchanger. This will make it possible to sharply reduce the consumption of electricity by energy-intensive equipment of the CTP (pumps, valves, etc.), the consumption of the amount of coolant, the consumption of cold water to lower the temperature of the coolant, and reduce the general tariffs for heat supply for consumers, which is relevant in wartime.

This will make it possible to significantly increase the reliability of the heating stations and their efficiency, which, in turn, will allow to reduce the number of service personnel, reduce the economic costs of preparing and supplying the heat carrier to consumers. Such work has been started, equipment is gradually being replaced at the CTP. Currently, our scientific team, in co-authorship with the employees of the CT system, is developing a general methodology for selecting the necessary technical equipment and appropriate software, conducting experiments on their consistency. After the end of the experiment, the results will be published.

As for the difficulties in preparing and conducting the experiment, there are certain limitations in terms of practical installation of expensive modern equipment and software, technical problems of installing sensors on the pipeline (currently for the pilot project it is planned to install them on the thermal frames of the CTP) and training specialists for the operation of new equipment. During the implementation of the pilot project, there was also a serious problem with attracting sponsors.

The third stage of modernization applies directly to consumers' buildings: by increasing the efficiency of heat carrier supply, each consumer will be able to independently control the microclimate in its room and timely regulate the costs of heating the home. However, the need for thermal insulation of buildings is decided by consumers individually.

As for the direct modernization of the equipment of the thermal power plants themselves, studies show that the modernization stages that have already been initiated are very similar to the CTP modernization.

The practical significance of the obtained results lies, to a large extent, in reducing the costs of consumers for services for heat supply and electricity consumption of their buildings, especially this applies to the difficult period of martial law, which Ukraine has been in for almost two years. Shelling of critical infrastructure, which includes heating points and heating networks, accelerated the pace of research and experimental work, namely scientific works on the introduction of modern technologies into the operation of heating points.

4. Conclusions

As a result of the study, the following scientific results have been obtained:

– The dependence of the coolant temperature drop on the normative values at a significant distance from the heating source is calculated.
– The dependence of a sharp drop in temperature and pressure indicators in the event of an emergency situation with subsequent determination of the location of the accident (leakage or rush) on the pipeline is derived.
– A complex of additional technical means for the equipment of the CTP heat exchanger is proposed.
– A complex of software tools for automating the operation of modern equipment of the CTP heat exchanger is proposed.

According to the authors of the article, these innovations will allow to increase the reliability of CTP work and the efficiency of their work, which, in turn, will allow to reduce the number of service personnel, reduce economic costs for the preparation and supply of coolant.

Conflict of interest

The authors declare that they have no conflict of interest in relation to this research, whether financial, personal, authorship or otherwise, that could affect the research and its results presented in this paper.

Financing

The research was performed without financial support.

Data availability

The manuscript has no associated data.

ISSN 2664-9969

Use of artificial intelligence

The authors confirm that they did not use artificial intelligence technologies when creating the current work.

References

1. Fahl, U., Dobbins, A. (2017). *District Heating in Europe. Europe's Energy Transition – Insights for Policy Making.* Elsevier Inc., 249–259. doi: https://doi.org/10.1016/b978-0-12-809806-6.00029-8
2. Koral, R. L. (2019). *District heating. AccessScience.* McGraw-Hill Professional. doi: https://doi.org/10.1036/1097-8542.201700
3. Nuorkivi, A. (2016). District heating and cooling policies worldwide. *Advanced District Heating and Cooling (DHC) Systems.* Elsevier Ltd., 17–41. doi: https://doi.org/10.1016/b978-1-78242-374-4.00002-1
4. Bourtsalas, A. C., Wei, J. (2023). Exhaust steam utilization in waste-to-energy strategies: From district heating to desalination. *Journal of Cleaner Production, 428,* 139389. doi: https://doi.org/10.1016/j.jclepro.2023.139389
5. *Zarubizhnyi dosvid rozvytku system tsentralizovanoho ta avtonomnoho teplo- ta elektropostachannia* (2016). Kyiv. Available at: https://ua.energy/wp-content/uploads/2018/01/5.-TSentralizovane-ta-avtonomne-teplozabezpechennya.pdf
6. Redkin, K., Ivanov, L. (2021). Vprovadzhennia systemy upravlinnia yakistiu v haluzi nadannia posluh naselenniu shchodo zabezpechennia teplopostachannia. *Vyrobnytstvo & Mekhatronni Systemy 2021.* Kharkiv, 159–161.
7. Ivanov, L., Kovalov, I. (2021). Yakist nadannia posluh opalennia naselenniu. *Vyrobnytstvo & Mekhatronni Systemy 2021.* Kharkiv, 171–174.
8. Dekilka krain YeS ne vidmovylysia vid tsentralizovanoho opalennia. Chomu? (2021). *Yevropeiskii pravdi.* Available at: https://www.eurointegration.com.ua/news/2021/11/5/7129897/
9. *Klasyfikatsiia typiv TsTP.* Available at: https://izocom.com.ua/klasifikatsiya-tipiv-tstp/
10. Zinchenko, A. (2021). Na porozi katastrofy: chomu Yevropa ne stala vidmovliatysia vid tsentralizovanoho opalennia. *Yevropeiska pravda.* Available at: https://www.eurointegration.com.ua/articles/2021/11/5/7129412/
11. Oliinyk, S. (2022). Yaku systemu teplopostachannia obraty mistam i vyzhyty. *Ukrainska enerhetyka.* Available at: https://ua-energy.org/uk/posts/yaku-systemu-teplopostachannia-obraty-mistam-i-vyzhyty
12. Ivanov, L., Kyrpota, F. (2021). Perevahy ta nedoliky v roboti isnuiuchykh avtomatyzovanykh teplovykh punktiv. *Vyrobnytstvo & Mekhatronni Systemy 2021.* Kharkiv, 199–121.
13. Kozlova, I. Yu., Lysenko, L. I. (2013). Pidvyshchennia efektyvnosti teplopostachannia sportyvnoho kompleksu NTU «KhPI». *Visnyk NTU «KhPI». Seriia: Enerhetyka: nadiinist ta enerhoefektyvnist, 59 (1032),* 92–100.
14. *DSTU ISO 9001:2015 «Systemy upravlinnia yakistiu. Vymohy»* (2016). Kyiv: DP «UkrNDNTs», 30.
15. *Directive 2010/31/EU of the European Parliament and of the Council of 19 May 2010 on the energy performance of buildings (recast)* (2010). Available at: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex%3A32010L0031

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