Some aspects of ecological engineering in modern heating systems of cities

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Abstract. This article outlines the results of a study of some aspects of implementation and use of ecological engineering elements in the heat supply systems of large urban agglomerations of the Russian Federation. It considers important problems associated with the definition of the term ecological engineering, defines the elements of ecological engineering that can be introduced into the sphere of heat supply of large urban agglomerations. It provides the data on heat energy losses in some subjects of the Russian Federation with harsh climatic conditions, in which heat supply to the large cities lasts for over 9 months a year. The article also identifies the main challenges the heat supply systems used in large metropolitan agglomerations of the Russian Federation face related to the modernization and digital transformation of the heat supply sector of Russian cities. It designates the main problems and opportunities of ecological engineering, which will allow, if widely implemented, providing remote control of the operation of district heating systems, controlling their temperature regime and pressure in pipelines, carrying out the necessary engineering calculations of the functioning of the systems relative to the topography of a particular urban agglomeration. In addition, the study outlines important components of the digitalization of district heating systems in cities to ensure their efficient, effective and, most importantly, safe for the ecosystems of large urban agglomerations, functioning. It has been established that ecological engineering in the district heating industry of large urban agglomerations has to be directed at conservation and restoration of the reserves of natural thermal resources, as well as the natural environment as a whole, by reducing the intensity of operation and emissions into the atmosphere that are produced during the processing of fuel resources.

1. Introduction
Modern society is developing in special conditions, both economic, political, sociocultural, and environmental. Undoubtedly, the human impact on the environment, taking into account these trends, is growing, and this influence is increasingly destructive [1]. This human influence exhausts natural resources and, ultimately, negatively affects the life of the society as a whole. In this regard, ecological engineering, which acts as an integrated institution combining modern environmental science with engineering in order to develop optimal concepts of the beneficial interaction of society [2] with its habitat, monitoring the state of the natural environment, as well as construction and restoration of ecosystems, is highly important for the efficient, effective and safe development of society.

Based on the essential content of ecological engineering, it is possible to identify those current goals that can be realized through its use, namely:
• restoration of distressed ecosystems, removal of contaminants, restoration and conservation of natural resources;
• ecological design of modern systems that ensures efficient and safe functioning, as well as the beneficial development of society [3].

The use and introduction of ecological engineering in large urban agglomerations with high population density is particularly important at present [4], as the most problematic environmental situation is observed in the major cities, which adversely affects the health and life expectancy of urban populations.

We should note however, that ecological engineering can be applied as an approach to the creation of appropriate safe habitats, both in general and in certain areas of public life [5].

For example, the environmental ecosystem of urban agglomerations located in adverse climatic conditions requiring the use of heating technologies for life support, undoubtedly suffers from outdated heat supply systems that pollute the atmospheric air. Correspondingly, the use of elements of ecological engineering during modernization of heat supply to large cities will facilitate the improvement of environmental conditions in this sphere of urban life [6].

Thus, it seems relevant to us to investigate some aspects of the application of ecological engineering, environmental innovations used in the modernization of heat supply systems in large urban agglomerations.

2. Goal of the study
Our main focus is to consider various aspects of the use of ecological engineering in the modernization of heat supply systems of large urban agglomerations.

3. Problem setup
The main goal of our study is to reveal the effectiveness and efficiency of ecological engineering in the modernization of heat supply systems of large urban agglomerations.

4. Research questions
The study will provide answers to the following questions:
• What are the main elements and goals of ecological engineering?
• Which problems arise when implementing elements of ecological engineering and environmental design?
• What are the specifics of the use of ecological engineering elements in the design and modernization of heat supply systems of large metropolitan areas?
• What is the effectiveness and efficiency of application of ecological engineering in the formation of ecosystems of major cities of the Russian Federation?
• What are the prospects for the use of ecological engineering in the heat supply systems of large urban agglomerations of the Russian Federation?

5. Research methods
The methods we used in our research are:
• theoretical (analysis of scientific literature, analysis and comparison of results of using ecological engineering in large urban agglomerations);
• empirical (observation, etc.).

6. Results and discussion
When it comes to researching problems related to ecological engineering, we should note that this is a fairly broad concept. Meanwhile, the ideas associated with the formation, monitoring, restoration, and optimal operation of ecosystems already arose in the 1960s.

They are evolving, complementing and transforming in accordance with modern realities, becoming increasingly important in determining the direction of sustainable and beneficial development of society.
In turn, we share the point of view of the researcher S.D. Bergen, who believed that ecological engineering, acting as a process that uses advances in environmental science and theory, adapts to environmental information techniques of designing systems and institutions of life in society in order to preserve or restore ecosystems of any type [7].

An important component of ecological engineering is environmental design, which was originally presented by H.T. Odum and other researchers [8] as use of natural energy sources as a primary approach to manipulate and control environmental systems.

As a result of ecological design or, as a matter of fact, any design, certain goals should be set, risks, problems and difficulties should be analyzed, various alternatives for solving the problems should be found, and, as a result, we should choose the best way to ensure the development of society, but also to preserve, and in the required cases, restore the habitat as an ecosystem [9].

The protection and restoration of at-risk ecosystems and natural areas, as well as the development of updated sustainable environmental systems to effectively address the challenges of the existence and further development of society, are important tasks that ecological engineering sets itself.

Ultimately, ecological engineering should help protecting the population from adverse, harmful and dangerous environmental factors, as well as ensuring the global or, if necessary, local conservation of ecosystems from the harmful effects of various factors, including human activities, and contribute to the development and improvement of the quality of human habitat.

Thus, considering the essence of ecological engineering, we should note that the use of its elements by society allows to solve very important problems of its existence and development related to the preservation of energy and resources, production facilities and assets, as well as the disposal of waste generated by the society.

We should note that modern ecological engineering is directly connected with digital technologies, digitalization and modernization of various systems facilitating the life of society. Indeed, it is difficult to imagine that the restoration and conservation of environmental systems and resources is possible without modernization and digital control of activities in the relevant areas of social functioning [10]. All these processes are directly connected with the digital eco-innovations that are capable of transforming the environment, facilitating its preservation, recovery, as well as aiding in further development of the human society.

Thus, considering the functioning of social groups within large urban agglomerations in the Russian Federation, we should note that the functioning of environmental systems of large cities is complex, they are difficult to restore as they are exposed, in most cases, to the negative anthropogenic influence.

We should note here that a large part of the large urban agglomerations in the Russian Federation are located in adverse climatic conditions, and the use of heat supply systems is required to ensure the livelihood of the population. These systems facilitate the life of large cities, all their infrastructure, and, accordingly, spend significant amounts of resources (gas, coal, fuel oil, etc.), and when they are used, the products of fuel processing are released into the atmosphere.

All these circumstances determine the need to use ecological engineering elements to ensure the efficient and effective operation of heat supply systems of large urban agglomerations to preserve urban environmental systems [11].

At the same time, the digitalization of processes in organizations providing heating for large urban agglomerations is highly important for ensuring the quality and environmentally friendly functioning of urban heat supply systems. Moreover, an important trend currently shared by many researchers [12], [13], [14] is the increasing dominance of energy-saving and resource-saving ideas and the idea of a "smart" city, functioning primarily due to the widespread use of efficient digital control systems, modernization and upgrades to modern technologies and materials of the fuel and energy complex, as well as the renewal of the housing and utilities sector [15].

Thus, we should note that the introduction of ecological engineering elements in the fuel and energy industry of large urban agglomerations is primarily related to the intellectualization (digital automation) of the fuel and energy complex as a whole, and its structural elements, heat supply systems in particular.
The introduction of ecological engineering elements into the heat supply systems of urban agglomerations involves the modernization of these systems, which would provide real-time and efficient responses to changes in the internal and external environment, quickly and flexibly restructure and integrate, and collaborate with related structures in the solution of heat supply problems of large urban agglomerations, and, ultimately, switch to the use of digital energy-saving technologies in an automated mode.

In general, in the Russian Federation, heat supply systems for large urban agglomerations are characterized not only by the low level of digitalization of processes and systems, but also by the wear and out-of-date state of the heat supply systems themselves.

In this regard, we are interested in the data on the losses of heat energy in some subjects of the Russian Federation over the past few years, which we have shown in Table 1 and presented for visibility in figure 1.

These subjects are chosen by us taking into account the specific similarity of climatic conditions of urban population in large urban agglomerations, the heating season of which usually lasts for more than 9 months a year.

Table 1. Heat energy losses in select subjects of the Russian Federation for 2016–2019, thousand Gcal.

| The name of the subject of the Russian Federation | 2016  | 2017  | 2018  | 2019  |
|-----------------------------------------------|------|------|------|------|
| Altai Territory                                | 2893.9| 2806.8| 3049.8| 3150.8|
| Krasnoyarsk Territory                          | 5092 | 5397.7| 6206.3| 6408.03|
| Irkutsk Region                                 | 3142.2| 3130.1| 3194 | 3215 |
| Novosibirsk Region                             | 3757.8| 3849.4| 4714.8| 4925.3|
| Omsk Region                                    | 2237.1| 1807.1| 2173 | 2754.2|
| Tomsk Region                                   | 1935.9| 1965.5| 2209.8| 2729.7|
| Trans-Baikal Territory                         | 1504.5| 1456.3| 1541.4| 1854.7|
| Tyumen Region                                  | 4755.8| 3969.6| 5686.3| 6013.5|

Figure 1. Heat energy losses in select subjects of the Russian Federation for 2016–2019, thousand Gcal.

According to the presented data, the losses of heat energy in these subjects of the Russian Federation invariably grow from year to year. This is primarily due to the significant degree of actual obsolescence and depreciation of fixed assets, including heat supply grids. For example, in Novosibirsk, located in
the Novosibirsk Region subject of the Russian Federation, the percentage of heating mains, the service life of which has exceeded the established one, according to some data, is up to 62% of the total number of heating mains in operation. In addition, there is a certain portion of damaged heating mains; in particular, the length of damaged pipelines in the city of Barnaul was 201 km, in the city of Kemerovo, 118 km, and in Krasnoyarsk, 103 km.

In addition, this state of heat supply systems and heat losses increases the amount of natural resources used for heating, and negatively affects the environmental state of cities, as the burning of fuel resources causes significant emissions of harmful substances into the atmosphere of cities.

With the data outlined, it seems obvious that it is necessary to introduce ecological engineering elements that would provide heat supply grid upgrades and rational management. Ultimately, it would allow to introduce energy-saving technologies and ensure a decrease in heat energy losses at the transportation stage, distribution and consumption of heat energy for heat supply to the cities, and, consequently, positively affect the environmental state in large urban agglomerations.

We should note that the main, in our opinion, direction of ecological engineering concerning the functioning of heat supply systems is their digitalization, introduction of digital information technologies and modernization of heat supply systems of large urban agglomerations in general.

Although, only about 60% of Russian enterprises operating in the heat supply sector of large urban agglomerations use elements of digitalization and information technologies in their activities.

At the same time, the future of heat supply systems lies with the computer-based digital heat supply systems of large urban agglomerations using software and technical complexes, the main element of which are the control devices, controllers. They facilitate input and output, processing, exchange and analysis of the information on the functioning of a respective heat supply grid that ensures its optimal, efficient and effective functioning on the scale of a large city.

In addition, in order to maintain the specified parameters of a heat supply system, one of its elements should be a digital automated control system. Such a system should operate in an on-line mode, collect and redirect information, containing a separate control unit processing all the incoming information. At the same time, the collection and processing of information should occur periodically and systemically, according to a set algorithm; also, it should process multiple inquiries originating from the client equipment.

We believe that heat supply grids and district heating substations of large urban agglomerations should also have their own digital control systems, which in case of an emergency or other situation should transmit relevant information for decision-making to an automated data center.

It is very important to provide, using the Internet system, a multi-process environment allowing direct access to any device matched with the object, and therefore, to any real-time data from the controlled technological object. In this case, virtual software acts as controllers.

The introduction of information and digital technologies allows facilitating remote control of the operation of district heating systems, controlling the temperature mode and pressure in pipelines or conducting the necessary engineering calculations. At the same time, these digital systems have to be formed as a geographic information system, which will allow modeling any processes within heat supply grids taking into account the topography of a specific urban agglomeration.

It is important for the monitoring and functioning of "smart" heat supply systems to be based, among other things, on the data of diagnostics and control of the internal state of heating mains, which would be carried out by robots. Using them, it becomes possible to remotely identify defects such as dents, chips, cracks, corrosion, etc. while finding their location and the size of the sighted defects. After the transfer of data from the robots, it can be automatically analyzed for the criticality of damage, the lifetime of such equipment taking into account the defect, as well as the choice of repair method.

In this manner, as a result of the use of automated engineering technologies, "smart" heat supply systems are created to provide a symbiosis of diverse and multi-format digital systems creating and operating a single complex of automated heat supply management systems of large urban agglomerations on the basis of a unified digital platform. In the end, this will allow to save up to 45% of the heat energy, which will directly save the fuel resources of the ecosystem.
7. Conclusions
The following conclusions can be drawn from our research:

- Ecological engineering is now becoming increasingly important and develops into an integral part of the life of society as it allows to correctly and efficiently use the natural resources, allowing the society to develop without destroying the ecosystems.
- Ideas and elements of ecological engineering can be used in various areas of society, as any use of ecological engineering elements involves the introduction of new technologies and processes, which in turn contribute to the preservation and restoration of habitats.
- In the Russian Federation, with numerous large urban agglomerations having a significant negative anthropogenic impact on the environment, the introduction of ideas and elements of ecological engineering in the heat supply industry is highly important.
- Ecological engineering in the heat supply sector of large urban agglomerations is primarily associated with the transition to the use of digital technologies and platforms providing a new digital approach to heat energy sources (resources), heat supply grids and heat consumers.
- Widespread introduction of information and digital technologies and digital geographical information systems will allow facilitating remote control of the operation of district heating systems, controlling their temperature regime and pressure in pipelines, carrying out the necessary engineering calculations of the functioning of the systems relative to the topography of a particular urban agglomeration.
- The symbiotic (integrative) approach to the introduction of ecological engineering into the heat supply industry of large urban agglomerations will allow for innovative renewal of heat supply grids, which will allow to save on heat consumption, and, consequently, will contribute to the preservation of ecosystems of large cities.

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