LIFE CYCLE MANAGEMENT OF CONSTRUCTION FACILITIES

УПРАВЛЕНИЕ ЖИЗНЕННЫМ ЦИКЛОМ ОБЪЕКТОВ СТРОИТЕЛЬСТВА

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Original Empirical Research

Improving the Efficiency of the Design Stage of the Life Cycle of the Heat Supply System of a Construction Facility

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Abstract

Introduction. The heat supply system is one of the most important infrastructural components of the engineering support of the construction site. However, the process of modeling its life cycle, particularly in terms of information support, has not been sufficiently researched in the academia.

One of the main stages of the life cycle of any engineering system is design. The need to increase energy efficiency, reduce the cost of designing and, thereby, building central heating systems, and improve the environmental situation highlights the special urgency of introducing innovative technologies, in particular, artificial intelligence that can become an effective tool for solving the existing problems. The aim of the study is to increase the efficiency of the design stage of district heating systems based on the use of artificial intelligence and to assess the prospects for such an approach.

Materials and Methods. The research methodology includes comparative analysis, modeling, statistical data processing and expert assessment. The research results can be used in the development of new approaches to the design of heat supply systems using modern digital technologies.

Research Results. The proposed concept of life cycle management of heat supply systems, which includes the sequential implementation of five key stages (from pre-design preparation to disposal) allows for an integrated approach to optimizing all of the processes. At the same time, the design stage, which determines the basic parameters of energy efficiency, efficiency and reliability of heat supply, is of critical importance. In the context of digitalization of thermal power engineering, the integration of intelligent automated systems implementing multifactorial algorithmic modeling and optimization calculations is becoming particularly relevant. Modern artificial intelligence-based solutions provide comprehensive automation of design and engineering work, including creating detailed information models of facilities, high-precision forecasting of heat consumption, hydraulic control and optimization of the energy balance of the system. The introduction of such technologies not only compensates for the lack of qualified specialists and improves the quality of project documentation, but also contributes to significant optimization of operational performance: reducing fuel costs and minimizing the carbon footprint through rational allocation of energy resources and reduction in greenhouse gas emissions.

Discussion and Conclusion. The article discusses modern approaches to automated design of district heating systems using artificial intelligence technologies. A technique based on the use of machine learning, neural networks, and optimization algorithms is proposed to improve design efficiency, minimize energy loss, and reduce operating costs.

Keywords: life cycle, life cycle management, heat supply system, district heating, construction site, artificial intelligence, computer-aided design, machine learning, optimization, energy saving

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Оригинальное эмпирическое исследование

Повышение эффективности этапа проектирования жизненного цикла системы теплоснабжения строительного объекта

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Аннотация

Введение. Система теплоснабжения является одним из важнейших инфраструктурных компонентов инженерного обеспечения строительного объекта. Однако процесс моделирования ее жизненного цикла, особенно в части информационного обеспечения, остается недостаточно исследованным в академической среде.

Одним из основных этапов жизненного цикла любой инженерной системы является проектирование. Необходимость повышения энергоэффективности, снижения затрат на проектирование и в последующем строительство систем центрального теплоснабжения, улучшения экологической ситуации подчеркивает особую актуальность внедрения инновационных технологий, в частности, искусственного интеллекта, который может стать эффективным инструментом решения существующих проблем. Цель исследования — повышение эффективности этапа проектирования систем централизованного отопления на основе применения искусственного интеллекта и оценка перспектив такого подхода.

Материалы и методы. Методология исследования включает сравнительный анализ, моделирование, статистическую обработку данных и экспертную оценку. Результаты исследования могут быть использованы при разработке новых подходов к проектированию систем теплоснабжения с применением современных цифровых технологий.

Результаты исследования. Предложенная авторами концепция управления жизненным циклом теплоснабжающих систем, включающая последовательную реализацию пяти ключевых этапов (от предпроектной подготовки до утилизации), позволяет обеспечить комплексный подход к оптимизации всех процессов. При этом критическое значение приобретает стадия проектирования, определяющая базовые параметры энергоэффективности, экономичности и надежности теплоснабжения. В контексте цифровизации теплоэнергетического проектирования особую актуальность приобретает интеграция интеллектуальных автоматизированных систем, реализующих многофакторное алгоритмическое моделирование и оптимизационные расчеты. Современные решения на базе искусственного интеллекта обеспечивают комплексную автоматизацию проектно-конструкторских работ, включая создание детализированных информационных моделей объектов, высокоточное прогнозирование теплопотребления, управление гидравлическими режимами и оптимизацию энергобаланса системы. Внедрение таких технологий не только компенсирует дефицит квалифицированных специалистов и повышает качество проектной документации, но и способствует существенной оптимизации эксплуатационных показателей: снижению топливных затрат и минимизации углеродного следа за счет рационального распределения энергетических ресурсов и сокращения выбросов парниковых газов.

Обсуждение и заключение. Рассмотрены современные подходы к автоматизированному проектированию систем централизованного теплоснабжения с использованием технологий искусственного интеллекта. Предложена методика, основанная на применении машинного обучения, нейронных сетей и оптимизационных алгоритмов для повышения эффективности проектирования, минимизации энергопотерь и снижения эксплуатационных затрат.

Ключевые слова: жизненный цикл, управление жизненным циклом, система теплоснабжения, централизованное теплоснабжение, строительный объект, искусственный интеллект, автоматизированное проектирование, машинное обучение, оптимизация, энергосбережение

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Introduction. The concept of integrated lifecycle management is a solid component of the modern management toolkit, acting as a major factor in optimizing functioning of diverse facilities, from individual products to large-scale projects and complex systems [1, 2]. This concept has a particularly important role to play in the construction industry, where it serves as a foundation for organizing effective operation and management of real estate, first and foremost, capital structures for a broad range of purposes [3, 4].

The introduction of a comprehensive approach to lifecycle management allows for the design of an integrated system of regulation and control at all stages of a facility life cycle, starting from the design and ending with the decommissioning stage. This approach ensures not only the rational use of resources at each stage, but also helps one to strike an optimal balance between the operational characteristics, economic efficiency and technological parameters of a facility [1–3].

In the context of the construction industry, this concept is gaining momentum as it allows accounting for the specific features of capital facilities, their long-term use and need for constant technical condition monitoring. At the same time, a comprehensive approach serves a solid foundation for innovative technologies, cost optimization and quality improvement of construction products at all of their life cycle stages [4].

In the construction industry, engineering systems are a vital component of infrastructural support of buildings and structures creating optimal or acceptable microclimate parameters and ensuring comfort. In spite of the high relevance of these systems for efficient operation of construction facilities, the field of modeling their life cycle, including information, has not been sufficiently studied in the academic environment and is currently fragmentary in research literature [5–7]. This results in a major gap in developing the theoretical foundations of engineering systems management throughout all of their operation stages.

Modern district heating systems must account for a host of factors, such as increasing urbanization, growing demand for comfort, and the ability to customize the microclimate. Traditional methods of designing and managing heat supply systems often fail to address these challenges resulting in design errors, unjustified material costs during construction, energy overruns, increased heat loss and reduced operational reliability.

Organizations designing heat supply systems are facing a few difficulties, including the need to increase energy efficiency, reduce the cost of designing and building systems, and tackle the environmental issues. Lately a major problem has been the lack of design professionals in the field of developing full-volume information models of heat supply systems. One of the key tools for addressing the above problems is the use of artificial intelligence (AI).

In the article the authors are exploring the possibility of improving the efficiency of the design stage of district heating systems based on the use of artificial intelligence, as well as the advantages and prospects of this approach.

Materials and Methods. As part of the study, a comprehensive analysis of the life cycle of the heat supply system of buildings and structures was conducted by means of the method of analogies, comparative and systemic synthesis. A detailed study of the stages of the life cycle, including design, installation, operation and modernization, is a testimant of the possibility of developing an adaptive control mechanism for the system at all its stages.

The subject of the study was the district heating supply system, and the main aim is to examine the use of artificial intelligence for complete design automation, a major life cycle stage, which provides energy effectiveness, efficiency, reliability and environmental friendliness of future heat supply systems.

The use of artificial intelligence technologies will enable one not only to systematize the accumulated scientific and practical data, but also to identify patterns of functioning of a heat supply system, which will open up new prospects for optimizing its life cycle and increasing energy effectiveness.

Research Results. In modern conditions of urban infrastructure development, district heating systems are characterized by a variety of constructive and technical solutions. The constantly expanding range of main and auxiliary equipment causes some difficulties while choosing a district heating system. This calls for a meticulous consideration of the numerous parameters and characteristics of each element of the complex engineering structure of a district heating system. The task of developing a methodology for selecting the optimal district heating system capable of providing the required level of efficiency, safety and economic feasibility at minimal operating costs is highly relevant. An integrated approach to addressing this problem calls for a comprehensive analysis of all the aspects of functioning of a system throughout its life cycle.

It makes perfect methodological sense to investigate the life cycle of a district heating system through implementing five consecutive stages: pre-design preparation, design, direct operation, modernization and disposal (Fig. 1).

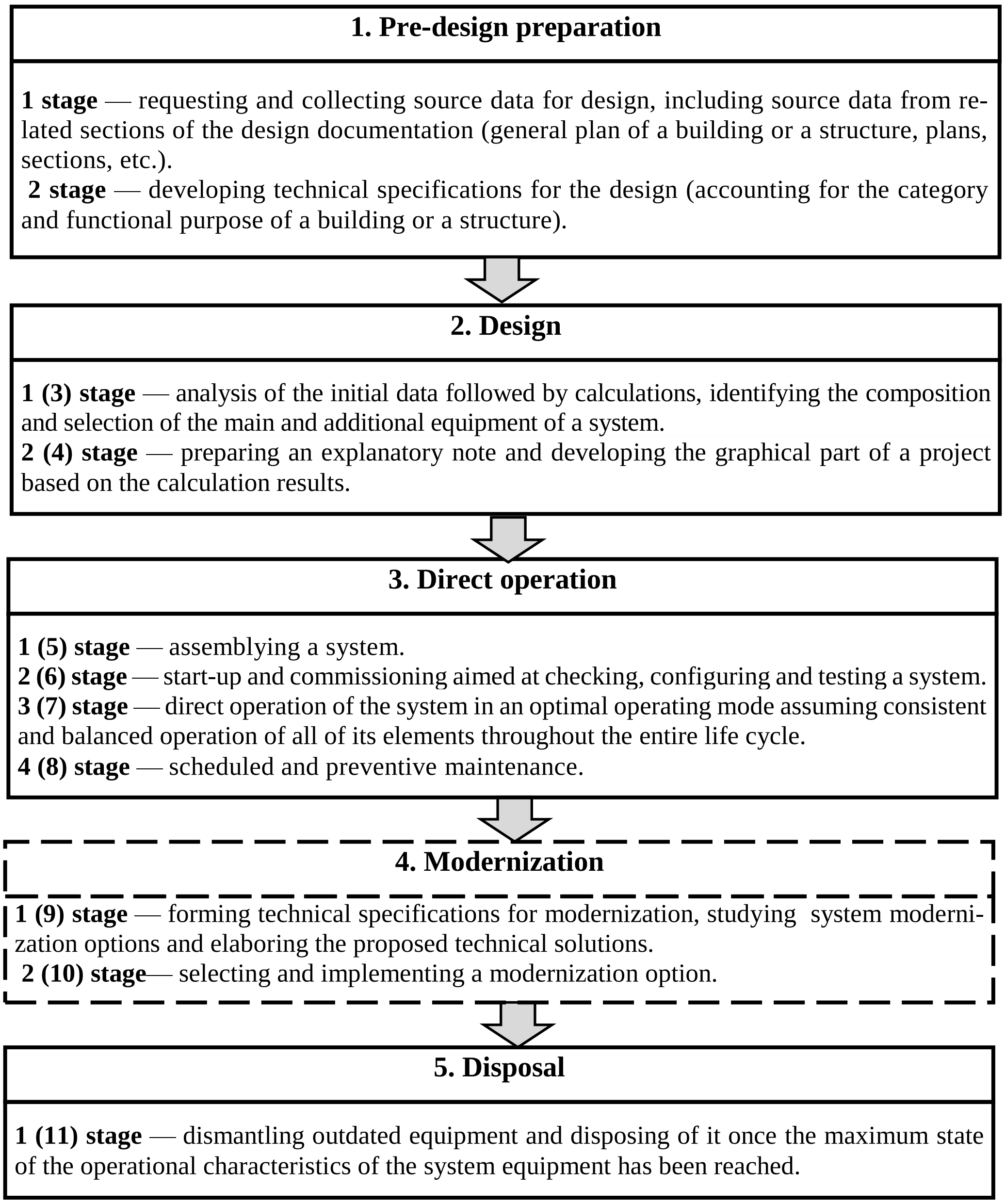

Fig. 1. Structure of the life cycle of the central heating system of a construction facility

Each of these stages is characterized by the implementation stages where the current state of a system, required set of works and the expected outcomes are identified. The analysis of the stages allows us to form a holistic view of functioning of the district heating system and to develop recommendations for optimizing its operation in the long run.

The design stage of district heating systems is particularly relevant, as this stage that is central for energy effectiveness and reliability of future heat supply facilities. However, the acute lack of qualified design specialists, particularly in the field of developing comprehensive information models of heat supply systems, might significantly undermine the quality of design documentation and the efficiency of future heating systems. As a result, the design time, number of design errors and as well as construction cost are on the rise due to some adjustments to be made [8].

Digital transformation of design serves as a strategic tool for improving the quality of design documentation and ensuring the reliability of thermal power facilities [9–11]. Automated design systems are a set of software and hardware tools that implement algorithmic modeling and optimization of design solutions. Their implementation makes it possible to mitigate the risks associated with a lack of highly qualified specialists and ensure a required level of quality of project documentation. The major task of computer-aided design is to create a system capable of analyzing input data (geographical, climatic, technical) and to generate optimal design solutions with minimal human involvement [12–14].

Artificial intelligence provides unique opportunities for complete design automation (information model development) of a heat supply system at all of its stages [15–17]. Artificial intelligence allows heat consumption to be accurately predicted, hydraulic modes to be stabilized and energy losses to be minimized. This enables one not only to reduce fuel costs, but also to address the environmental issues by cutting CO_2 emissions.

Automation of the design stage in the lifecycle of a district heating system allows the stages to be included implementing the following:

– developing an engineering digital model of an area (engineering surveys);

– placing heat consumers on the topplane;

– applying main and intra-block heating networks based on a geodetic substructure;

– developing a longitudinal profile of the heating networks;

– collecting and analyzing data (collecting data on the heat consumption, temperature fluctuations, etc.);

– conducting hydraulic calculations and developing thermal and hydraulic modes of a system;

– developing a mathematical model (based on the collected data, a mathematical model is created for predicting thermal and hydraulic conditions with a high degree of accuracy).

The use of artificial intelligence in the design phase of district heating systems adds a new element — machine learning – for predicting heat loads.

Artificial intelligence is trained mostly on regulatory documents in order to identify the technological limitations and best examples of design solutions for developing optimal "thinking" of artificial intelligence.

The following are applicable for accurate prediction of thermal loads:

1) regression analysis methods and neural networks (e.g., LSTM networks) capable of accounting for time series of data such as ambient temperature, historical heat consumption, and socio-economic factors;

2) genetic algorithms for optimizing network configuration (in order to identify the optimal topology of a heating network, minimize a pipeline length, pressure loss and construction cost; each solution is encoded as a chromosome, and optimization includes crossing, mutation and selection of the most effective options);

3) neural network models for hydraulic calculations (artificial neural networks are used to simulate hydraulic modes in complex branched networks; network training is based on the data obtained from numerical simulations of the behavior of complex systems or processes for quick evaluation of the system parameters — pressure, coolant flow — while operating conditions change);

4) integration with GIS systems (to account for some geographical factors (relief, location of buildings, infrastructure), it is suggested that the design system is integrated with geographic information systems (GIS); this enables automatic generation of heating network maps and spatial data analysis);

5) testing and optimization (the developed system is tested on real data and then optimized for a maximum efficiency);

6) validation and verification of the digital information model of the heat supply system;

7) transfer of a digital information model of a heat supply system using XML schemas to the next stage of the lifecycle of a system.

Discussion and Conclusion. Introduction of automated design systems is not merely a technological trend, but rather an objective necessity owing to the current requirements for energy effectiveness and reliability of district heating systems. Digital transformation of design is setting the stage for new quality of design solutions ultimately resulting in optimization of capital investments and operating costs at all of the stages of the life cycle of thermal power facilities.

The use of artificial intelligence in the design of heat supply systems provides a few major advantages:

– addresing the lack of qualified design engineers;

– a sharp reduction in the design time while improving the quality of projects;

– a possibility of employing the resulting digital information model of a heat supply system at subsequent stages of the life cycle of a system.

Designing a heat supply system by means of artificial intelligence is a promising area that is capable of greatly improving the efficiency of heat and power management processes. Introduction of such systems facilitates energy-saving, addresses the environmental issues and creates a comfortable living environment. Such technologies are expected to be further developed and improved, making them even more sought-after in the field of thermal energy.

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AL Tikhomirov: formation of the basic concept, analysis of the research results, correction of the conclusions, graphic design, revision of the manuscript.

EP Lysova: aims of the study, analysis of the research results, correction of the conclusions.

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