Assessment of system effects in the operation of an integrated heating and cooling systems in North

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Abstract. The work examines the current issues of development, management and optimization of integrated systems in the world and in Russia. The developed algorithm for evaluating the systemic effects of an integrated heating and cooling system in the conditions of the North is described. A qualitative and quantitative assessment of socio-economic, operational, and environmental effects is obtained using the example of the city of Yakutsk. The work carried out a technical and economic calculation, technical parameters of the energy system operation and volumes of CO^2 emissions reduction. The use of waste heat by absorption chillers in the production of cold can reduce electricity costs by up to 29% per month of total consumption and save up to 519 million rubles per year. The implementation of the integrated heating and cooling system technology can reduce CO^2 emissions by up to 58 tons.

Keywords: integrated energy systems, integrated heating and cooling systems, trigeneration, district cooling, waste heat, system effects.

1 Introduction

1.1 Background

Modern trends in energy - the development of energy technologies contributes to closer technological interconnection at all stages: transformation, generation, transport and energy storage. Also, telecommunications and information technologies are widely developing, providing additional opportunities for coordinated management of energy supply systems. This leads to the idea integrating electricity, heat, cooling, and gas supply systems into a new structure in the form of an integrated energy system (IES). Analysis of global energy research indicates a rapid growth of interest in IES. Many countries actively engage in IES research, with the highest growth in the number of articles in this field observed in China [1]. Currently, optimization, control, and planning of integrated energy systems are relevant issues, including combined cooling, heating, and power systems, renewable energy sources, and hybrid energy storage systems. IES can include photovoltaic panels, wind turbines, cogeneration plants, gas boilers, energy storage systems, absorption chillers,

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power converters, etc. The primary objectives are to reduce carbon dioxide emissions and mitigate climate change. High investment costs in renewable energy systems, which typically do not yield desired economic results, are reduced through the implementation of high energy efficiency measures and CO^2 emission reductions achieved by IES [2-4].

In Russia, teams from ISEM SB RAS, Institute of Power Engineering, INRTU, JSC ENIN, etc. are actively working on integrated energy systems. At the moment, work is being carried out mainly in groups of performance management tasks. Work has been carried out on the use of a multi-agent approach in the modeling and management of IES, work on managing the demand of active consumers, digitalization of IES, etc. [5-9]. As the authors themselves note, less attention is paid to development tasks than to the tasks of managing the functioning of these systems both in Russia and in the world.

This work focuses on the development tasks of integrated heating and cooling systems (IHCS) in the conditions of the Russian North [10]. Such a system allows for the production of three types of services in a single technological cycle - electricity, heat energy, and cold (trigeneration). In a northern country like Russia, IHCS technology based on absorption chillers can be relevant due to the significant amount of waste heat from thermal power plants during the summer [11, 12]. This article focuses on the system effects that occur when an energy system operates in trigeneration mode. The work assesses the socio-economic, operational, and environmental effects of an integrated heating and cooling system in the city of Yakutsk.

1.2 Aim and methodology

The aim of this article is to provide a quantitative and qualitative assessment of system effects, which includes a technical and economic calculation, balances of production and consumption of electricity, heat, cold and the amount of CO^2 emissions reduction. Figure 1 presents a flowchart of the assessment algorithm.

Stage I. Consumer cooling demand modeling is performed using Building Energy Modeling (BEM) software. Buildings are categorized into archetypes and simulated using eQuest software. Then, consumers are allocated to sources of cooling – Central Chilling Point (CCP). A detailed description of the modeling stages is provided in reference [11].

Stage II. A map-scheme of the Integrated Heat and Cold Supply System (IHCS) pipeline system is created using the QGIS geospatial information system. The tracing of the cooling pipelines is done in parallel with the existing quarterly district heating pipelines.

Stage III. Pipeline diameters are selected based on the difference between the return and forward pipelines $\Delta t=10$ °C and the average flow speed $\omega_{average}=1.5$ m/s. In future work, it is planned to carry out hydraulic calculations of the cooling pipelines system using the SOSNA software package [13].

Stage IV. Design of a pipeline system for DCS [14].

Stage V. Scenarios for the city's cooling load are chosen. Conservative option with connection of 20% of consumers to DCS. This option involves connecting blocks with the best technical and economic indicators to the district heating system. The maximum option is to connect all buildings in the city that have the technical ability to connect to the system.

Stage VI. Calculation of discounted payback periods for selected options. Technical and economic comparison of two options for air conditioning buildings: district cooling on absorption chillers and electric local split air conditioners.

Stage VII. Balances of production and consumption of electricity, heat and cold.

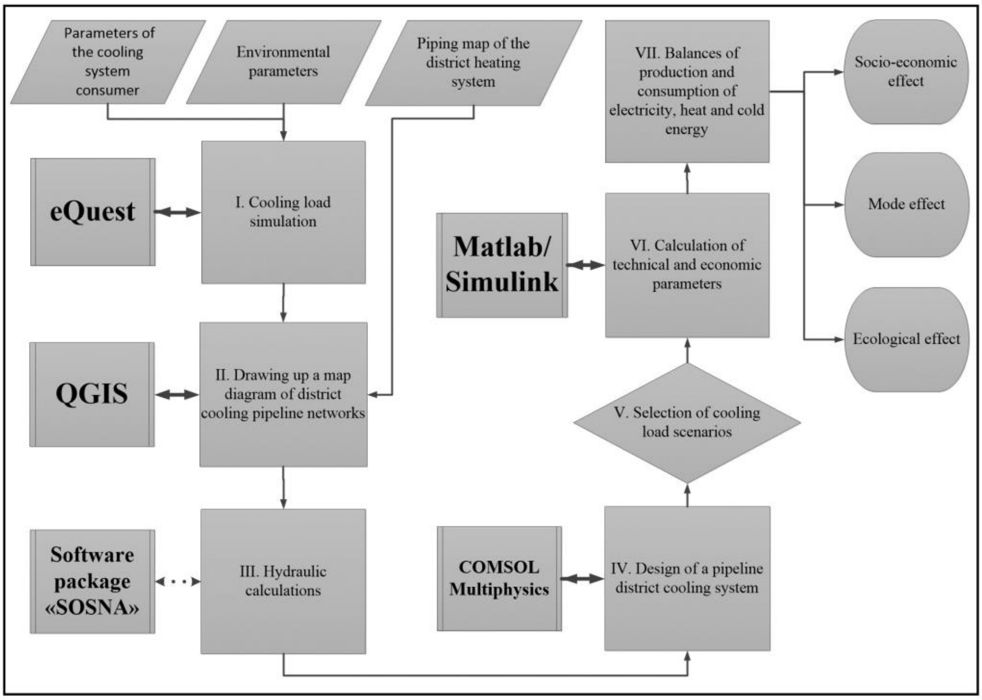

Fig. 1. Algorithm flowchart.

2 Results and discussion

Calculations were performed using the example of the Yakutsk city. The research object is the buildings in the city located near the main district heating pipelines that have the potential to utilize waste heat with absorption chillers. There are 1071 buildings categorized into 7 archetypes. The modeling was done for the year 2019 with a 1-hour time step.

During the calculations, the following systemic effects, arising in the city of Yakutsk's energy system under trigeneration mode, were identified:

Economic effect. The discounted payback periods of the IHCS were 6 years and 8 years, the savings in annual electricity consumption for cold production in the monetary equivalent of 106 and 519 million rubles for the conservative (20%) and maximum (100%) options, respectively. Construction of the district cooling system will create a minimum of 81 work rates for servicing the new equipment. Systemic changes in the air conditioning sector should increase the overall requirements for the quality and standard of living. Such changes can lead to increased human productivity in various areas of life: education, healthcare, culture, sports, transport, etc.

Mode effect. The implementation of the integrated heating and cooling supply system technology can significantly reduce electricity consumption by up to 29% per month by utilizing waste heat as an energy source for cooling instead of electricity. Consequently, it is possible to reduce electricity generation during the summer, thereby reducing fuel consumption or increasing electricity sales on the wholesale market. Some of the energy system parameters are listed in Table 1.

Ecological. The implementation of the IHCS technology can reduce CO^2 emissions by 12 and up to 58 tons for the conservative (20%) and maximum (100%) options, respectively. And also, reduce the leakage of freons R22, R134a, and hydrofluorocarbons by air conditioners.

Table 1. Operating parameters of the energy system.

Changing operating parameters	June	July	August	Year
Conservative option (20%)				
Electricity saving percentage, %	4,0	6,4	3,3	0,8
Cold consumption, thousand Gcal	15	25	14	54
Increasing the useful supply of thermal energy, %	125	139	111	102
Maximum option (100%)				
Electricity saving percentage, %	17,3	28,9	13,8	3,7
Cold consumption, thousand Gcal	77	127	68	272
Increasing the useful supply of thermal energy, %	225	298	206	112

3 Conclusion

The implementation of integrated heating and cooling supply system technology on the scale of the city of Yakutsk can create significant system effects. This can contribute to improving the quality of life for the population, enhancing the efficiency of energy systems, and reducing harmful emissions. Importantly, there is no change in installed capacity due to the seasonal nature of the demand.

Structural changes in the energy system may occur when this technology is adopted in dozens of cities across Russia, resulting in a substantial shift in power and electricity flows and a significant reduction in electricity consumption during the summer.

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