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OPTIMIZATION OF HEAT CONSUMPTION IN CENTRAL HEATING SYSTEMS AT COMMERCIAL FACILITIES

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Abstract

Rising energy prices and stricter environmental regulations are exacerbating the problem of inefficient heat consumption in the commercial sector. Central heating systems of office buildings, shopping malls, and industrial complexes are often characterized by excessive thermal energy consumption, which leads to significant economic losses and a negative impact on the natural environment. The purpose of the study is to study the directions and trends of optimization in the field under consideration (taking into account modern technological capabilities, and economic factors).

There are disagreements in the professional community about the priority of measures to improve energy efficiency: some experts prefer improving the thermal insulation of buildings, others — the introduction of intelligent control systems, and others — the integration of renewable energy sources. The present study demonstrates that the greatest effect is achieved with a systematic approach combining various initiatives.

The conclusion is formulated that in the current conditions and the future, a comprehensive application of modern thermal insulation materials, highly efficient heating equipment, intelligent management mechanisms, and alternative energy sources is required.

The article is of interest to engineers-designers of heating systems, energy managers of commercial facilities, specialists in energy efficiency of buildings, and heads of companies interested in optimizing operating costs and improving the environmental friendliness of their real estate.

Keywords Alternative energy sources, intelligent control systems, commercial facilities, optimization of heat consumption, thermal insulation, central heating, energy efficiency.

INTRODUCTION

The rational use of thermal energy in commercial facilities represents a pressing issue considering rising energy costs and tightening environmental regulations. Central heating systems, commonly found in office buildings, shopping centers, industrial complexes, and similar structures, are often characterized by low efficiency and excessive heat consumption. In this regard, researchers in scientific studies examine innovative methods and various technological solutions to minimize heat loss and optimize the performance of heating systems in the commercial sector.

The research problem lies in the fact that inefficient use of thermal energy in central heating systems of commercial properties leads to significant economic losses and a negative environmental impact. There is a growing need for the development and implementation of solutions that optimize heat consumption, taking into account the specifics of buildings, modern technological capabilities, and economic factors.

Methods and Materials

The study utilizes comparative analysis, systematization, and generalization. Contemporary scientific works that address specific aspects of the topic were analyzed. Several publications focus on innovative technologies and effective solutions in the field of heating and heat supply. D.K. Karapetyants examines efficient developments in residential and commercial buildings [1], while V.P. Plaksina analyzes the current state and prospects for the development of innovative technologies [2]. S.N. Chebysheva, S.I. Bliznyuk, and M.V. Pralnikova address the issue of energy-efficient heat consumption design [5]. These studies emphasize the importance of implementing modern developments.

Other researchers focus on alternative energy sources and low-temperature heat supply systems. A.V. Fedorov explores the use of geothermal heat pumps for heating commercial and infrastructure facilities [4], a promising direction. S.V. Chicherin analyzes options for transitioning to a low-temperature heat supply [8], which can significantly reduce heat loss during transportation. In an international context, S. Boahen and J. Choi investigate trends in cascade heat pumps [9], which provide high efficiency across a wide range of temperatures.

Some works are dedicated to the measurement and accounting of thermal energy, which is highly significant for optimizing heat consumption. O.V. Stukach, I.Yu. Popov and P.A. Zorin apply the total variation method for error recognition in the study of commercial heat energy accounting data [3]. V.P. Chipulis addresses the adequacy of thermal energy measurement in open systems [6, 7], which is especially relevant for commercial properties with high consumption levels.

Finally, L. Yang and co-authors present a model of economic optimization for dispatching a microgrid with a compressed air energy storage solar hub [10], which demonstrates a comprehensive approach that incorporates renewable energy sources as well as storage systems.

Thus, the authors employ various approaches to address the topic, emphasizing the importance of systematic actions to improve the energy efficiency of commercial facilities, with technological, economic, and environmental aspects taking center stage.

RESULTS AND DISCUSSION

The first step in the process of optimizing heat consumption is a detailed analysis of the sources of losses. Upon reviewing modern publications, it is found that the main channels of heat loss in commercial properties are as follows (Fig 1):

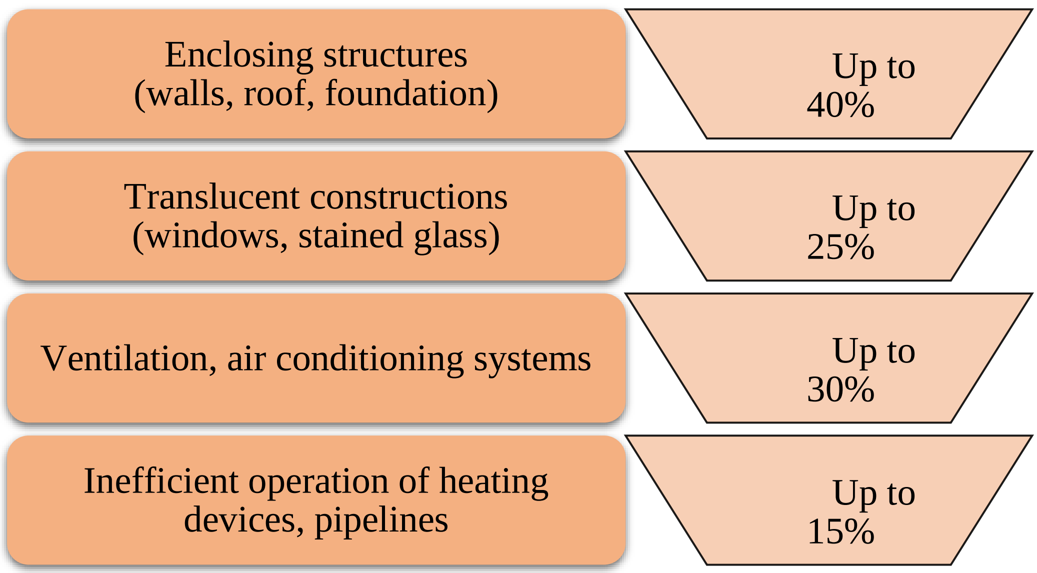

Fig. 1. Identification of key sources of heat loss [3, 5, 9]

For an accurate assessment of heat losses, modern diagnostic methods are applied, including thermal imaging surveys, which allow for the identification of areas with increased heat output. The analysis of the obtained data serves as the basis for the subsequent development of a set of measures for building thermal modernization.

Next, it is reasonable to focus on the characteristics of technological solutions that enable energy efficiency improvement. They are listed in the diagram (Fig. 2).

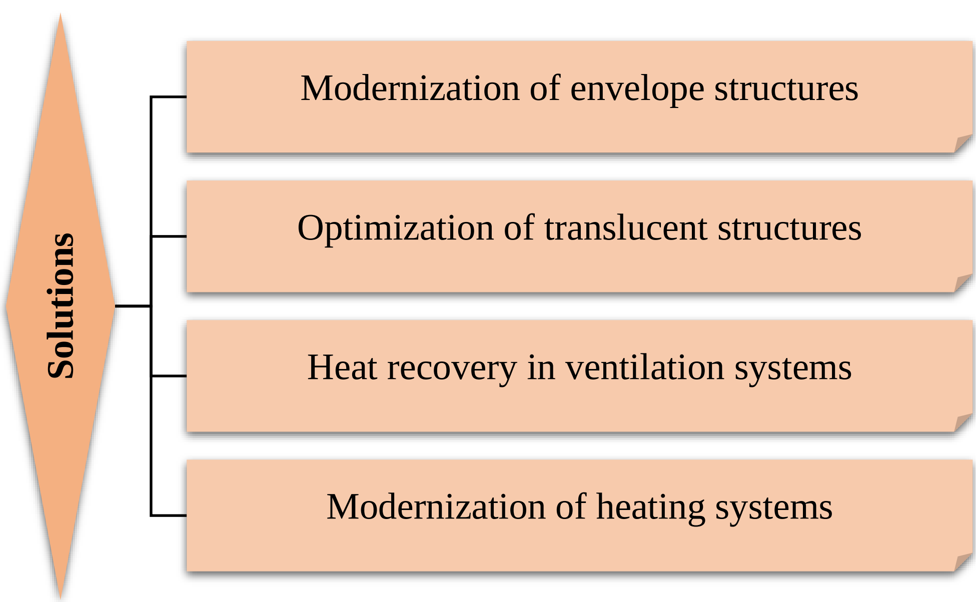

Fig. 2. Systematization of technological solutions for energy efficiency improvement [1, 5]

Thus, one of the key areas for optimizing heat consumption is improving the thermal insulation properties of building enclosures. The use of modern insulation materials (primarily polyurethane foam or aerogel) significantly reduces the thermal conductivity of walls and roofs. Innovative facade systems with ventilated gaps not only enhance the thermal protection properties of a building but also prevent condensation, thereby increasing the durability of the structures.

From a technological standpoint, it is also relevant to mention the replacement of outdated windows with modern energy-efficient models featuring low-emissivity coatings and inert gas filling between the panes, which can significantly reduce heat loss through transparent components. The use of dynamic glazing with adjustable transparency ensures optimal lighting and thermal balance in rooms, depending on the time of day, season, etc.

Furthermore, the introduction of heat recovery systems into ventilation units allows for the utilization of up to 85% of the thermal energy contained in the exhaust air. The use of rotary or plate-type devices enables efficient heat exchange between supply and exhaust airflows, significantly reducing the load on the heating system.

Regarding the optimization of heating system operation, it relies on the following key aspects:

- Installation of automated individual heating substations (IHS) with weather-dependent regulation, allowing flexible control of the heat carrier supply based on external climate conditions;

- Implementation of zoned control using thermostatic valves and room thermostats to maintain the set temperature in individual rooms;

- Use of variable-frequency drives on circulation pumps, which helps regulate the flow of the heat carrier and electricity consumption;

- Application of highly efficient heating devices with improved heat output, such as bimetallic radiators and forced convection solutions.

A key element in optimizing heat consumption in modern commercial buildings is the use of intelligent energy management systems (IEMS). These systems integrate data from numerous sensors, analyze the nuances of room usage, and take into account weather forecasts to create optimal algorithms for heating equipment operation.

The intelligent energy management system (IEMS) performs several crucial functions, which are listed in Figure 3.

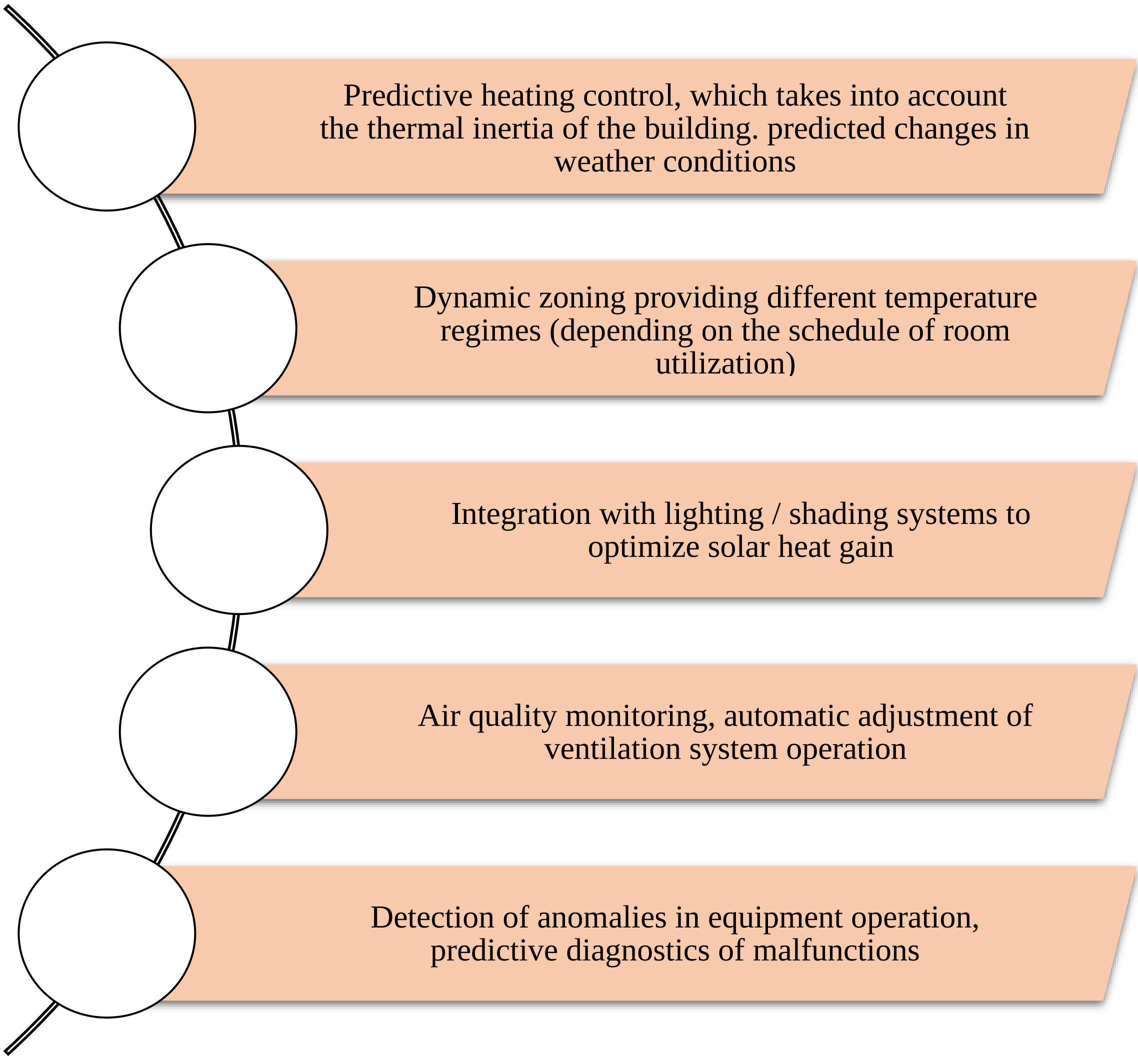

Fig. 3. The main functions of the intelligent energy management systems [2, 5]

The use of intelligent energy management systems allows for heat energy savings of up to 30-40% compared to traditional control systems [2].

The integration of renewable energy sources (RES) into the heating systems of commercial facilities represents a promising direction for optimization. The most effective technologies in this area include:

- Heat pumps utilizing low-potential heat from the ground, air, or wastewater. Modern systems significantly reduce primary energy consumption;

- Solar thermal systems integrated into building facades and roofs, capable of providing up to 60% of hot water needs and partially covering heating loads during transitional seasons;

- Trigeneration systems based on gas engine plants that simultaneously generate electricity, heat, and cooling, achieving an overall efficiency of up to 90%;

- Biomass boilers that use local renewable resources (e.g., wood waste, pellets) as fuel [10].

The combination of various technologies within hybrid heating systems optimizes energy resource costs and significantly reduces the carbon footprint of commercial properties.

Next, it is appropriate to focus on the economic aspects of the topic discussed in the article.

The implementation of energy-efficient technologies requires significant initial investments, but the long-term benefits of their implementation are substantial. An analysis of the life cycle of heat consumption optimization projects shows that the payback period for comprehensive measures is 3-7 years (depending on the initial condition of the facility and the chosen technological solutions) [2].

The key economic advantages are systematized in the diagram (Fig 4):

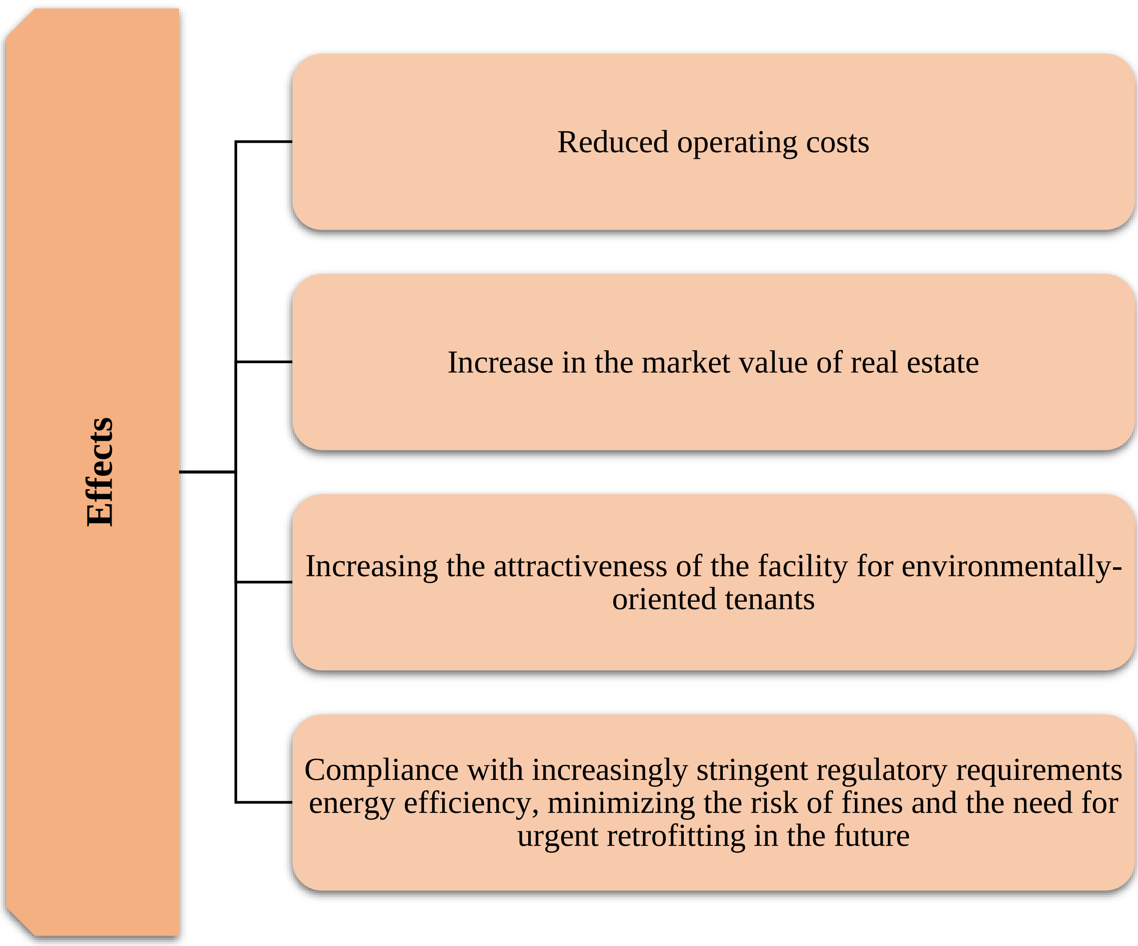

Fig. 4. Highlighting the main economic effects (compiled by the author)

The algorithm proposed in Table 1 is an original development aimed at improving the efficiency of heat consumption management. It includes stages from analyzing the current state to full integration with digital platforms.

Table 1 – Recommended algorithm for integrating heating systems of commercial facilities into the concept of "smart cities" (compiled by the author)

Stage	Action	Result
1. Assessment of existing infrastructure	Analysis of current heating systems at the commercial facility: their energy efficiency, technical condition, and modernization potential.	Identification of "bottlenecks" and opportunities for improvement.
2. Implementation of sensors and monitoring systems	Installation of sensors for temperature, humidity, pressure, and other indicators. Connection of the monitoring system to cloud platforms for data collection and analysis.	Continuous real-time monitoring of heating system indicators.
3. Integration with digital platforms	Connection of the heating system to city resource management platforms via the Internet of Things (IoT). Utilization of weather data, occupancy rates, and energy tariffs.	Automatic control of the heating system based on external data and forecasts.
4. Optimization of energy consumption	Application of artificial intelligence algorithms for predicting heat consumption and adapting system operation. Introduction of energy-efficient modes.	Reduction of energy costs, and improved comfort at the facility.
5. Performance analysis and adjustment	Regular analysis of heat consumption data, costs, and achievement of energy efficiency goals. Adjustment of system operation.	Increased operational efficiency with minimal costs.
6. Scaling and integration	Expansion of successful solutions to other facilities. Connection of additional intelligent systems for comprehensive building management.	Full integration of facilities into the "smart city" infrastructure.

The proposed algorithm is expected to effectively integrate the heating systems of commercial facilities into the concept of "smart cities," which will contribute to reducing heat consumption, increasing energy efficiency, and creating suitable conditions for sustainable management of urban resources.

CONCLUSIONS

Optimizing heat consumption in central heating systems of commercial facilities is a multifaceted task that requires the application of innovative technological solutions and a systematic approach to energy resource management. The integration of modern insulation methods, high-efficiency heating equipment, intelligent systems, and renewable energy sources enables significant reductions in heat consumption while simultaneously enhancing user comfort and minimizing environmental impact.

Future research in this area should focus on the development of new materials with improved thermal insulation properties, the enhancement of predictive energy consumption management algorithms, and the optimization of hybrid heating systems. Special attention should be given to the integration of commercial heating systems into the concept of "smart cities," which will allow for the realization of the potential of interconnected buildings within a unified energy network.

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