ANNOTATION

of doctoral dissertation (PhD) in the specialty 6D072900 - «Civil Engineering» of Tukhtamisheva Ainur Zokirovna on the topic «**Economic and technical justification for the optimal level of energy efficiency of residential buildings in Kazakhstan**»

Relevance of work: Implementation and improvement of energy saving, and energy efficiency is currently one of the main tools for modernizing industry, housing and communal services, transport sector and other sectors of the economy of the Republic of Kazakhstan. Successful reorganization of energy saving, and energy efficiency enhances the country's energy and environmental security. In addition, ensuring increased energy efficiency stimulates the introduction of new innovative technologies and solutions, which in turn stimulates active interaction between the development of science and technology transfer.

The above studies of the dissertation are due to the growth in the volume of housing construction, which entails an increase in the consumption of various types of energy, the production of which entails the intensive use of the country's natural resources and environmental pollution due to greenhouse gas emissions. Scientifically grounded determination of the optimal thermal insulation of external fences of residential buildings is the primary task on the way to increasing the energy and environmental stability of the entire state.

To ensure the economic stability of the state, one of the most important tasks is to increase the level of energy efficiency in the construction industry. Our homeland is rich in various energy resources and the government pays special attention to the development of the country's energy sector. “It is important not to forget that by investing in the construction of roads, houses and other infrastructure, we define the physical and technological appearance of our cities for many years to come. Therefore, it is important to ensure the transfer of the latest technologies both in construction and in the production of building materials. We have good opportunities for this”.

Rational energy saving, increasing the energy efficiency of the economy are the most fundamental tasks of the XXI century not only for the Republic of Kazakhstan, but also for the rest of the world, inclusive, the achievement of which is possible only through the introduction and implementation of organizational measures in the field of energy conservation and the development of the use of energy-saving technologies. “In fulfilling this task, it is important to apply new construction methods, modern materials, fundamentally different approaches in the design of buildings and planning of urban development. It is necessary to establish increased requirements for the quality, environmental friendliness and energy efficiency of buildings. Buildings under construction and existing ones and infrastructure facilities must be equipped with intelligent control systems. This will increase the comfort for the population, reduce the consumption of electricity, heat, water, and will stimulate natural monopolists to increase their efficiency. "

Analyzing all the messages of the First President of the Republic of Kazakhstan, it is necessary to emphasize that every year attention is paid to the development of not just the construction sector of the country, but the formation and transition to all kinds

of improvements in environmental performance during the construction of facilities, striving to switch to the side of green construction.

Every year, energy-efficient construction is gaining more and more development all over the world, so new buildings appear, built according to the most modern technologies, with increased requirements for thermal protection and improved energy consumption characteristics.

In the Republic of Kazakhstan, the residential sector consumes 13.5% of electricity and 24% of thermal energy and is the third largest consumer of heat and electricity in the country. The housing stock of Kazakhstan is more than 270.9 million square meters, most of which are old apartment buildings with centralized heat and energy saving, which today on average consume 2-3 times more energy per square meter, than in Western Europe houses. Thus, according to research data, in Kazakhstan, the consumption of thermal energy in buildings is about 270 kW per sq. meter per year, while in Western Europe, the same indicators average 100-120 kWh per sq. meter per year. In the countries of the European Union, complying with the requirements of the European Directive on energy efficiency in construction, by 2020 the consumption of thermal energy will be reduced to 20-30 kWh per sq. meter of heated area per year, and most of the energy consumed will be generated from renewable energy sources.

In the last decade, as a result of economic development, the volume of housing construction in Kazakhstan has increased significantly. The annual increase in the volume of housing commissioned is from 10% to 36%. Since 2005, housing construction has been one of the priority areas of the Development Strategy of Kazakhstan until 2025. State programs for the development of housing construction, approved by the President of the Republic of Kazakhstan, were aimed at ensuring the development of the construction of affordable housing by reducing its cost and providing long-term concessional loans. According to official data, the share of energy consumption in the residential sector in Kazakhstan doubled by 2016, compared to 2010. Thus, an increase in the volume of construction in the residential sector means an increase in the level of energy consumption and, accordingly, greenhouse gas emissions. In order to prevent an increase in energy consumption in construction, it is necessary to significantly change the concept of construction in relation to the energy efficiency of buildings.

Various concepts of energy efficient construction are used in the world, but many are characterized by the following sets of measures:

- reduction of heat losses of buildings by increasing the thermal insulation properties of external fences,
- reducing energy consumption by introducing highly efficient engineering systems for heating, ventilation, and lighting,
- reducing the consumption of non-renewable energy by replacing it with energy produced from renewable sources.

Increasing the level of thermal insulation of external fences is a primary task on the path to energy efficient construction because the use of highly efficient, complex and expensive engineering systems is advisable only with limited and controlled heat consumption in buildings. Both the entire system for improving the energy efficiency

of buildings, and separately taken complex measures to improve the thermal insulation of external fences must comply with the principle of economic feasibility - investments in energy efficiency measures must pay off within a specified period of building operation due to energy savings. Therefore, the economic and technical substantiation of the optimal level of thermal insulation of fences of residential buildings is the main task of this dissertation work.

The object of the dissertation research is the energy efficiency of new residential buildings in the city of Almaty and the Almaty region.

The subject of the dissertation research is:

- economic and technical substantiation of the optimal level of thermal insulation of external fences of new residential buildings,
- analysis of ways to reduce carbon dioxide emissions by increasing the energy efficiency of buildings and using renewable energy sources for heat production.

Purpose of the research:

To determine the level of thermal insulation of external fences of residential buildings, corresponding to the optimal distribution of total costs during the service life and to propose effective ways to reduce environmental pollution with emissions from the production of thermal energy.

This goal is achieved by solving the following tasks:

1. Conduct an analysis of ways to improve the energy efficiency of buildings and methods for determining the optimal thermal protection of external fences to identify opportunities and ways to reduce the use of thermal energy in the residential sector.
2. Determine the technical and economic indicators of sources of heat energy production, design solutions for external fences and heat-insulating materials to determine the optimal level of heat-shielding characteristics of building envelopes in the Almaty region.
3. Adapt the EU methodology for determining the requirements for thermal protection of buildings at the lowest cost during the life of the housing construction of Almaty in order to optimize the level of thermal insulation of building envelopes and comparability of the results.
4. Determine the recommended standard indicators of thermal insulation of external fences of residential buildings and analyze the reduction in thermal energy consumption using the example of an exemplary building with design and optimal heat-shielding characteristics.
5. To develop directions for the introduction of optimal thermal protection of the building, energy-efficient engineering systems and energy production from renewable sources on the dynamics of reducing the consumption of thermal energy and the corresponding emission of greenhouse gas in the Almaty region.

Scientific novelty of the work:

1. The heat-shielding characteristics of the enclosing structures of residential buildings for the city of Almaty and the Almaty region were determined and justified, corresponding to the optimal distribution of total costs during the life of the building, taking into account the dynamics of economic and energy circumstances;

2. Integrated solutions for thermal insulation of enclosing structures and the use of engineering systems of residential buildings have been developed, providing low and zero emissions of carbon compounds and helping to reduce environmental pollution in Almaty in the conditions of intensive development of housing construction.

Implementation of research results:

The results of the research of the dissertation work were used in the production process of the design and construction organization LLP "PSO Building Expert", where for the first time a scientifically based analysis of the energy efficiency of the implementation of various measures to improve the thermal insulation of external elements of residential buildings, and the use of innovative engineering systems to reduce energy consumption in buildings, and reducing greenhouse gas pollution. Implementation act No. 13 dated 07/09/2021. To be given to the dissertation in Appendix A.

Reliability of the obtained results of conclusions and recommendations:

The reliability of the obtained results, conclusions and recommendations is based on the use of climate data of the Almaty region, on the study of the project of a model building created as a result of studying the practice of housing construction in the region, on the use in calculations of real prices for energy, building materials and work in the city of Almaty. The reliability of a certain optimal level of thermal insulation of building envelopes was also verified by comparison with the optimal indicators of thermal protection of enclosures and thermal energy consumption in other countries, taking into account the difference in climatic conditions, prices for thermal energy, building construction and building materials.

Approbation of work:

The results of the dissertation research were discussed:

- at the international scientific and practical conference: "Innovative and science-intensive technologies in the construction industry" (Almaty, 2018);
- at the XXIII International Scientific and Practical Conference "Experimental and Theoretical Research in Modern Science" No. 14 (22) (Russian Federation, Novosibirsk, 2018);
- at XIV Miedzynarodowej naukowi-praktycznej konferencji, «Wykształcenie i nauka bez granici - 2018», Volume 13 Przemyśl: Nauka i studia (Poland, Warsaw, 2018);
- at the international scientific and practical conference: "Modern trends in architecture and construction: energy efficiency, energy saving, BIM technologies, problems of the urban environment" (Almaty, 2019, 2020);
- at 20-th International Multidisciplinary Scientific GeoConference Surveying Geology and Mining Ecology Management, SGEM 2020 «Energy and Clean Technologies» (Republic of Bulgaria, 2020);
- at an expanded meeting of the Faculty of General Construction of the International Education Corporation (IEC) in 2021

The practical significance of the work:

- the optimal heat engineering characteristics of the enclosing structures of residential buildings have been determined, which can be used for design and

construction until a significant change in the economic situation in the country and in the region;

- the dissertation presents methods of optimization and acquisition of calculated data that can be used to update the optimal heat engineering indicators of both residential and other buildings, taking into account changes in the economic, ecological and social environment;

- recommendations are made to reduce the growth of energy consumption in connection with the growth in housing construction, and to stimulate energy efficiency by redistributing state energy subsidies for the implementation of energy efficient measures in the construction of buildings.

- the results of the study were introduced into the design and construction organization «PSO Building Expert» LLP in the construction of a one-story brick house in the Almaty region.

Publications:

12 papers have been published on the topic of the dissertation, including four articles published in scientific journals included in the List of recommended ones by the KKSON MES RK; five articles in the materials of international scientific and practical conferences; one article in an international interdisciplinary scientific conference, indexed in the Scopus database, with a percentile of 17 and a CiteScore of 0.6; including 2 more articles, in a journal indexed in the Web of Science and Scopus databases, one with a general engineering percentile of 14 and a CiteScore of 0.4, the other with an engineering (miscellaneous) percentile of 83 and a CiteScore of 4.7.

Structure and scope of work:

The dissertation work consists of an introduction, four chapters, a conclusion, a list of references and appendices. The volume of work is 106 pages of typewritten text and contains 17 tables, 51 figures, 33 pages of 113 title list of used sources and 10 appendices.

The first chapter consists of the analysis of the situation of increasing the level of energy efficiency of buildings. Where the main issue of the global trend of increasing energy efficiency and reducing greenhouse gas emissions in construction was considered, the chronology of the implementation of requirements for energy efficiency in construction, the main goals, ongoing activities and expected results to improve the energy efficiency of construction in Kazakhstan were considered.

Key findings from the **first chapter**:

The main reasons for increasing the requirements for energy efficiency of buildings in the world were energy crises, high prices for energy resources, improvement of thermal insulation materials, increasing requirements for internal comfort and environmental protection.

Improvements in energy efficiency in construction are reflected in the reduction of environmental pollution by reducing the overall consumption of thermal energy, more intensive use of passive energy and the transition from fossil primary sources of heat production to renewable energy sources.

Building materials, which are an important component of the construction process, also have a significant impact on the environment, since their production,

transportation, installation and subsequent disposal also use energy, the production of which increases carbon dioxide emissions.

As a result of the development of the economy, the volume of housing construction in Kazakhstan has increased significantly, thereby increasing the consumption of thermal energy and, accordingly, greenhouse gas emissions into the atmosphere. There are state requirements for the energy efficiency of buildings, various organizational, technical, technological, economic and other measures are being implemented aimed at reducing the amount of energy resources used, but they have no scientific justification from the point of view of construction economics and environmental protection. Determination of the level of thermal insulation of the external fences of residential buildings, corresponding to the optimal distribution of total costs during the operation life and the proposal of effective ways to reduce environmental pollution with greenhouse gas emissions from thermal energy production, is the main goal of this study.

In the second chapter, we analyzed scientific research and technical achievements in the field of improving the energy efficiency of housing construction and the scope of determining the certification of energy efficiency of buildings, reviewed the world's concepts for the design, construction of energy efficient buildings, and identified the technical aspects of increasing the energy efficiency of buildings.

Key findings from the **second chapter:**

The result of scientific research carried out in the field of energy efficiency of buildings is the selection of economically viable solutions to improve the energy efficiency of buildings and reduce environmental pollution with carbon dioxide emissions from many alternatives that are comparable to each other, refer to the same period, climatic conditions and economic environment, taking into account all costs associated with the full cycle of the existence of the building, taking into account changes in economic and financial conditions.

Increasing the level of thermal insulation of external fences is the primary task on the way to energy efficient construction, because the use of highly efficient, complex and expensive engineering systems is only advisable with limited and controlled heat consumption in buildings.

A review of global concepts for the design and construction of energy efficient buildings has identified the main directions for the development of the construction sector in this area:

- application of progressive methods of planning and design of buildings;
- use of innovative building materials and engineering systems;
- certification of buildings with assignment of energy efficiency classification;
- government incentives for energy efficient construction.

In the world building practice, many different technical solutions have been developed and applied to improve the energy efficiency of buildings and reduce carbon emissions, including building design, materials used and engineering systems. The objectives of this dissertation research are to evaluate the effectiveness and applicability of these solutions in the climatic, economic, construction and energy conditions of Almaty.

The third chapter presents calculation methods and databases for determining the optimal level of thermal insulation of residential buildings. Climatic data and requirements for the climatic conditions of the internal microclimate in Almaty and Almaty region were determined, the terms of operation of buildings and their structural elements were considered, a design period of 30 years was used for optimal thermal insulation of residential buildings. An analysis of representative residential buildings was carried out, where the object of the study was 2 residential buildings in the city of Almaty and the Almaty region. The initial investment for the thermal insulation of building envelope elements was calculated, the energy consumption of residential buildings during the service life was determined, and the calculation of the annual costs for increasing the thermal insulation of the building envelope was made.

Key findings from the **third chapter:**

To obtain generalized data on the optimal level of thermal insulation of elements of enclosing structures and elements of residential buildings in the study region, it is necessary to create a model of an exemplary building corresponding to the typical geometry of buildings currently being designed and being built in Almaty and the region, with typical elements of the shell and power systems, with a typical structure energy and construction costs, corresponding to the climatic conditions of the geographic location.

To identify the relationship between the optimal thermal protection of the building and the conditions of internal temperature conditions, seasonal energy consumption should be calculated during one heating season with two different durations - 182 and 212 days, corresponding to the outside air temperature at the beginning and end of the heating season + 10 and + 12 degrees.

The calculation of heat losses through the structures and elements of the building to determine the optimal thermal insulation should be carried out according to the schemes that best correspond to the ratio of the growth of the thickness of the thermal insulation and the reduction of heat losses:

- for walls and roofs - as heat transfer through 1 m2 of these structures,
- for windows - as the difference between heat transfer and solar heat input through 1 m2 of window,
- for the floor - first of all through the floors of the entire model building, then use the average value per 1 m2 of floor area.

In the calculations, it is inappropriate to use different air temperatures in residential premises, since the optimization of thermal protection was carried out for external fences and elements, regardless of the type of premises that they protect from the external environment.

To determine the effect of the price of thermal energy on the optimal level of thermal insulation of enclosing structures, it was necessary to use different prices for thermal energy. To achieve the actual situation of the corresponding optimization results, the calculations used the prices of energy from heat networks and natural gas supplied to residential consumers in the Almaty region.

The fourth chapter presents the results of the optimal level of thermal insulation of residential buildings and its impact on reducing the heat loss of buildings and the subsequent reduction of greenhouse gas emissions. The results of a step-by-

step calculation of the optimal thermal insulation of the enclosing structures of exemplary residential buildings are given, using the recommended values of the heat transfer coefficient of partitions, the energy efficiency characteristics of exemplary residential buildings were calculated. An analysis and calculations of the possibilities of reducing greenhouse gas emissions by increasing the energy efficiency of new residential buildings are made.

Key findings from the **fourth chapter:**

As a result of the study, it was found that the heat consumption of a residential building with optimal heat transfer coefficients of enclosing structures will be on average 1/3 lower compared to the existing practice of thermal insulation.

State regulation of energy prices without financial incentives for energy saving measures reduces the interest in investing in energy efficiency, because these investments will not be compensated by the money saved.

The low cost of thermal energy and the shorter heating season result in lower annual building heating costs. This does not contribute to increasing the energy efficiency of buildings, improving the thermal comfort in the premises and saving energy resources.

A stable economic situation (lower discount rate) leads to the stability of the annual costs of heating buildings during the billing period. This economically justifies the increase in the thermal insulation of buildings and the reduction of energy consumption over the entire life cycle.

An analysis of the total heat energy costs for windows and other translucent barriers using the example of a reference building showed that the current relationship between energy prices and the cost of implementing energy saving measures hinders the introduction of innovative energy saving measures in the Almaty region.

The results of the study show that without changing the energy efficiency and primary sources of heat in buildings, carbon emissions from the residential sector in the Almaty region will almost double over the next 30 years.

Implementation of the energy efficiency measures identified in this study into new buildings can reduce environmental pollution by up to 8 times during the billing period.

Increasing the thermal insulation of building envelopes, using more efficient windows can halve CO2 emissions, especially in single-story residential buildings, which have a significantly greater impact on CO2 emissions reduction than multi-family buildings.

Mechanical ventilation systems with heat recovery in one-story residential buildings are much more effective in reducing CO2 emissions than in multi-family buildings, so their installation in single-story residential buildings should be a priority.

Single-story residential buildings with heat pumps and photovoltaic power plants become completely environmentally friendly and do not affect CO2 emissions. It is impossible to achieve such a result in multi-apartment buildings with existing technologies due to the larger ratio of roofing and heating area, but the above measures also significantly contribute to reducing environmental pollution.