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Retrofitting Measures for Existing Housing Stock in Kazakhstan

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***Abstract*—**Residential buildings fund of Kazakhstan was built in the Soviet time about 35-60 years ago without considering energy efficiency measures. Currently, most of these buildings are in a rundown condition and fail to meet the minimum of hygienic, sanitary and comfortable living requirements. The paper aims to examine the reports of recent building energy survey activities in the country and provide a possible solution for retrofitting existing housing stock built before 1989 which could be applicable for building envelope in cold climate. Methodology also includes two-dimensional modeling of possible practical solutions and further recommendations.

***Keywords*—**Energy audit, energy efficient buildings in Kazakhstan, retrofit, two-dimensional conduction heat transfer analysis

I. Introduction

RESIDENTIAL buildings stock in Kazakhstan takes its roots back from the Soviet Union era. The country (USSR) was in need of a mass-scale, quick and low-cost housing construction after the Second Great War of 1941-1945. The preference has been given to the industrial housing construction - building neighborhoods of 5- and 9-storey prefabricated houses. This not only reduced the cost of construction and allowed to increase the input of housing, but also made it more comfortable than shared apartments, only because each apartment was designed at the rate of settlement of one family rather than several. The dwellings represent standardised frame-panel, concrete-paneled or brick three- to five storied buildings so called “Khrushchevkas” that have been adapted when Nikita Khrushchev directed the Soviet government. The design and solutionve has been broadly disseminated to all 15 republics of USSR and in turn in due time it had boosted the industry and economy of USSR. “Khrushchevkas” exhibit a number of similarities in their design, building envelope and its elements, ownership structure and even user habits [1]. Most of them were initially seen as temporary, to be demolished after 25 years. Others were built as permanent, and had to serve for 50 years. However, it has been said that their service life could be extended to 150 years if the renovation measures are taken in time. Although the buildings had helped in solving the housing issues for people at that time, still some problems such as bad noise and lack of thermal insulation exist. The insulation is important at any dwellings, but in continental climate, it becomes inevitable.

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II. Energy and the Construction Sector in Kazakhstan

A. Energy

The economy of the Republic of Kazakhstan is highly dependent on traditional energy sources like coal, oil and gas. It accounts for an estimated 20-30% of GDP, over 50% of fiscal revenues and 60% of exports [2]. As well as consuming the huge amount of energy sources, the country emits greenhouse gases. It is known as the third largest emitter in Eurasia [3].

Kazakhstan had ratified Kyoto Protocol to the UN Framework Convention on Climate Change and proposed to reduce emissions to 15% below 1990 by 2020. At the same time, Kazakhstan has chosen the path of Forced Industrial-Innovative Development with expected increase of coal use up to 45% for energy generation by 2020. Coal is known as the main source for heating supply and the most polluting energy source in terms of CO_2 emissions. One of the options for tackling climate change could be obtaining energy with zero carbon intensity from alternative energy sources. However, the share of renewable energy sources in the country is significantly low, although it is expected to rise up to 3% of whole energy mix by 2020 [4].

Another way of helping to meet targeted reduction is to increase the efficient use of energy. According to the Ministry of Environment, 80% of GHG pollution in the Republic of Kazakhstan comes from the energy sector, 90% of which generated by energy and power production sector. Building and residential sectors are found to be the third biggest consumer of heat and power energy in the country after industrial sector [5].

B. Current Construction Activities

At the moment Kazakhstan is experiencing the massive growth of construction structures to meet housing demand. Since the beginning of the 2000s, the construction market in Kazakhstan is growing rapidly (Fig. 1). [6] It could be observed from the chart that the general trend of construction is decreasing in case of inclusion of construction during last years of USSR. Although there was a recession time after USSR collapse, after gaining the independence Kazakhstan construction activities have been growing despite the economic crisis in 2007.

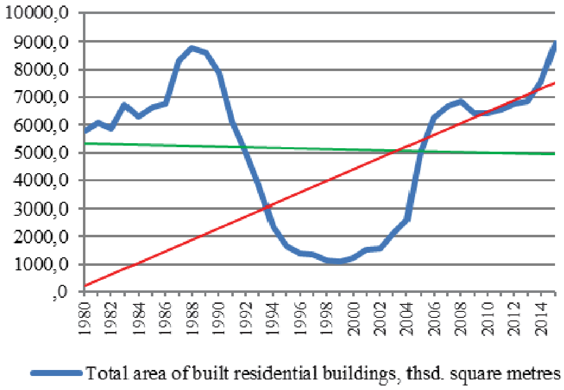

Fig. 1 The dynamics of residential buildings operating start in Kazakhstan for the period between 1980-2015 [6]

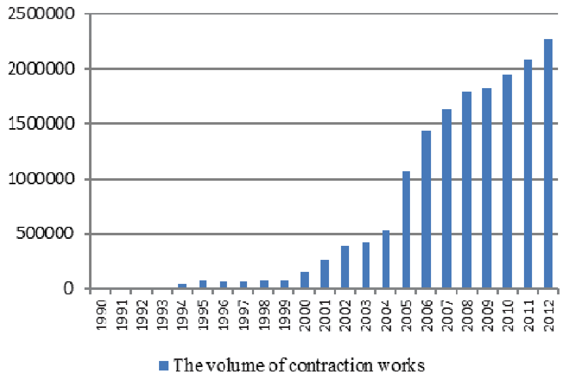

Fig. 2 Construction activity main indices dynamics [6]

National statistics data show the volume of construction works (Fig. 2) starting from 2000 had rose by 15 times [6].

Although new buildings are developed in accordance with local energy efficient standards, they still exert enormous pressure on the natural environment. Increasing energy use in cities is caused by a matter of urban population growth. The average rate of annual urbanization in Kazakhstan currently stands at 0.9% and urban inhabitants are expected to reach 66.3% of the country's population by 2030 [7]. New buildings (residential, schools, hospitals, commercial centers), transportation systems (parking), distribution systems are being constructed to meet the requirements and demand for larger populations. The expected increase in population, housing construction will consequently lead to higher energy consumption coming from space heating and air-conditioning systems, greater environmental damage, and development of unsustainable energy supply that will result to energy insecurity.

C. Energy Consumption in Construction Sector

According to the housing and utility sector of Kazakhstan the housing sector consumes about 11% of electricity and 40% heat energy nowadays. Experts estimate about 70% of the buildings, do not meet modern requirements (especially in the construction of buildings 1950-1980) due to the heat loss through building envelope that amounts up to 30% [8].

To reduce the energy demand and consumption by the different industrial sectors, Kazakhstan should also shift towards the sustainable use of the resources through implementing the low-carbon strategies in construction sector as well. Energy consumption in built environment could be reduced through new designs, technologies, and materials, proper control and the use of effective engineering systems, and energy management systems, by considering such factors like building orientation, shape, insulation, use of high efficiency windows etc.

III. Energy Audit

According to the Law of the Republic of Kazakhstan "On energy saving and energy efficiency" there is a number of adopted regulations, including the "Rules of the energy audit in industrial plants and buildings", "The rules for determining and reviewing the energy efficiency classes of buildings, structures and facilities" that require obligatory implementation of energy audits to evaluate the energy saving opportunities and implement the necessary measures [9].

Within the framework of Governmental programme on modernization of housing and communal services for 2011-2020 the energy surveys of the old building stock energy efficiency analysis had been conducted for different climatic zones. The purpose of the energy audit of the buildings is the development of measures aimed at reducing the consumption of fuel and energy resources. As a result, 954 residential buildings and 151 social facilities had been surveyed in 16 regions across the country between 2010 and 2013 [8].

The results of the reports on energy surveys performed within the framework of the budget program 007 "Kazakhstan Center for modernization and development of housing and communal services" have been analysed [10]. The total number of the reports of surveyed houses in 2010 amounted to 117 units, of which according to Fig. 3, 33,3%, 43,6% and 5,1% of dwellings fall under the low (E), very low (F) and underlevel (G) energy efficiency categories. The average thermal transmittance value of the walls is U=1 W/m^2·C.

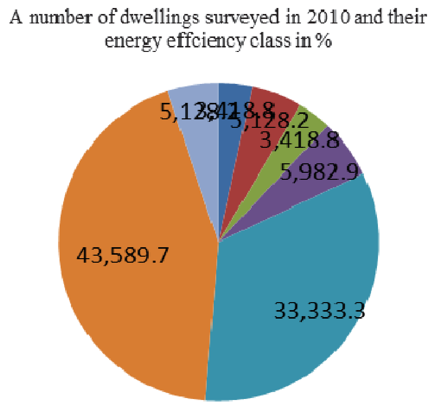

Fig. 3 Energy efficiency classes of dwellings surveyed

During the energy survey, the infrared screening technique is used. Thermographic analysis is useful for assessing a building's energy performance, both for its envelope and its facilities. Moreover, it helps to identify construction and energy problems of the buildings like design, construction, installation or building malfunctions, and envelope. Some examples are shown. The thermal images clearly show the heat loss through the building, Figs. 4-6.

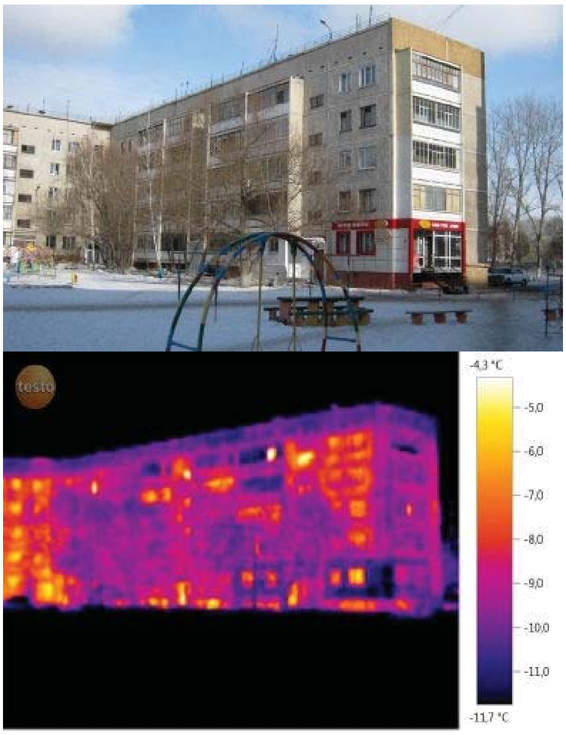

Fig. 4 Heat loss through the walls

In the period up to 1996 in the country, 4-9-storeyed buildings were mostly built, for which normalised specific need for useful heat energy for heating purposes of buildings (average) according to SN RK 2.04-21-2004* is 85 kJ / (m^2·°C·d) [11].

Energy efficiency class A-C is set while design and operation of new and renovated public buildings, class D - during the operation of these buildings. Assigning a class D at the design stage is not allowed. Classes E-G are recommended to specify for the operating buildings (set into operation until 1996).

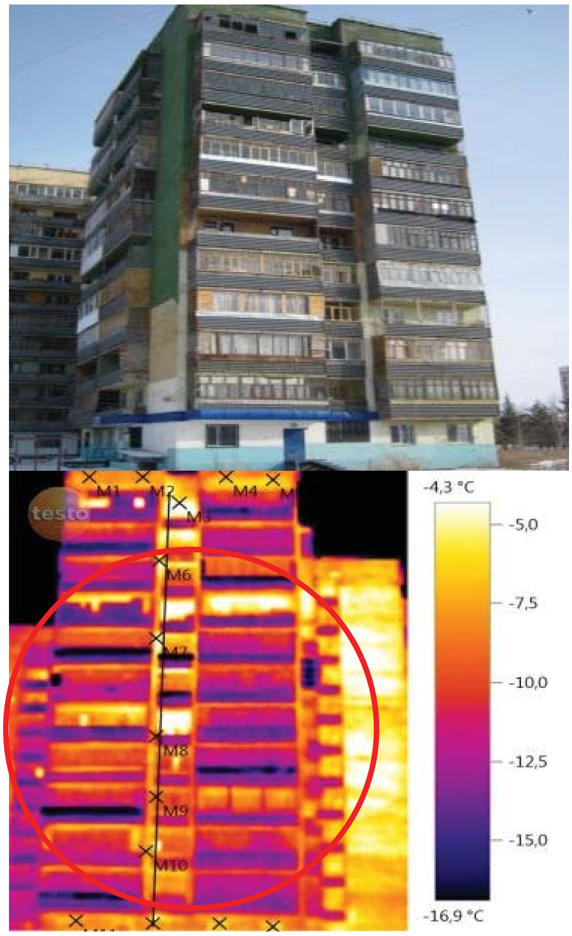

Fig. 5 Heat loss through the walls and windows

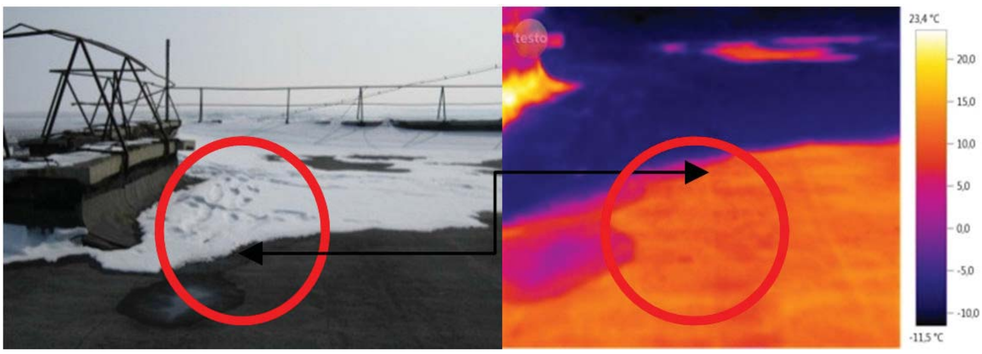

Fig. 6 Heat loss through the roof

TABLE I
ENERGY EFFICIENCY CATEGORIES [9]

Alphabetical reference	Reference name	he value of the calculated deviation (Or measured normalized in accordance with GOST 31168) in the value of the specific thermal energy demand for heating the building q_h^{des} from normative value, %	Recommendations
		At the design and operation of new and renovated buildings	
A	High	Less than minus 50	Recommended economic incentives
B	Advanced	From minus 10 to minus 50	The same
C	Normal	From 0 to minus 9	-
		During operation of new and renovated buildings	
D	Degraded	From plus 1 to plus 25	Penalties
		When using the existing buildings	
E	Low	From plus 26 to plus 75	Desirable reconstruction of the building
F	Very low	From plus 76 and to plus 120	Reconstruction of the building in the long term
G	Underlevel	More than 120	Reconstruction of the building in the near future

According to the energy audit reports [10], there is an energy saving potential of 30% in the old residential stock. Energy use in old housing sector can be reduced significantly through implementing a package of measures to upgrade the energy efficiency of an existing housing stock. The main measures suggested are: applying better insulation of the envelope (walls, roof and floor) and upgrade of window glazing from single to double or triple glazing to reduce air infiltration. However, a comfortable temperature in the old residential buildings (built according to SNIP II-3-79*), will be equal to about 24 °C or more, instead of 21 °C (according to the norms). For the region of Astana, one degree of overheating in rooms almost equivalent to 4% of losses [12], [13], [14]. Even the insulation will be improved, due to the centralized heating the amount of energy will still remain the same and would further cause the overheating. People would open the frames for getting fresh air and loose the heat again.

Calculations show that the performance of existing residential buildings constructed by SNIP II-3-79* (i.e., without improving the thermal performance of building envelopes), automatic heating system control (with a coefficient of efficiency equal to 0.9) will reduce specific heat consumption for heating and ventilation of multi-storey residential building does not exceed 10% (for Astana region).

Remarks:

1. The end result of processing by the heating system of measurement is to determine the actual heat demand during the heating season. Specific measure heat for heating the house allows to compare with each other and with the standard, as the energy efficiency of buildings is assessed on this indicator [11].
2. The automated control system of heat, regulate the flow of heat, depending on the outside temperature. And for compliance in the supply and return lines of the heating system water temperature (actual temperature) and the required schedule can judge the correctness of the heating mode [12].

IV. MODELING RESULTS

Improving the thermal protection of buildings could be achieved by improving the design solutions of external walls. One of the effective solutions is the use of ventilated external walls with heat recovery effect [15]. The working principle is that air flows through air channel (air gap) buried in wall, enters the room and provides sufficient steady flow of fresh air in the room. Using such method allows the outside air passing through the air gap to warm up during the heat exchange process occurred due to the pressure difference. As a result, part of the heat leaving the building through the outer wall is returned back into the room through the air. The advantage of this method is energy saving and improved moisture conditions of outside fences.

To evaluate the energy efficiency and local temperature patterns of the proposed solution (Fig. 7), modeling of two-dimensional heat-transfer effect has been done in THERM software [16].

The proposed solution represents the insulation thickness d = 125 mm, density ρ = 70 kg/m^3, thermal conductivity λ = 0,038 W/(m·°C), and light insulated screens d = 25 mm, ρ = 50 kg/m^3, λ = 0,033 W/(m·°C), ventilated air channel d = 25 mm.

A. Data Input

The input parameters are as follows: Thickness of structural layers, temperature of internal t_{int} = 21 °C and external air t_{ext}= -36 °C, flow direction inside-out.

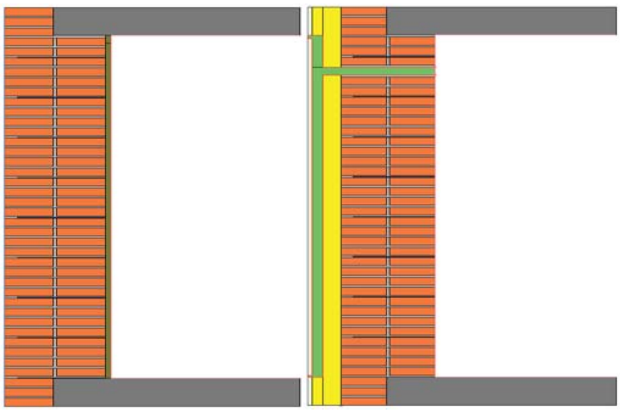

Fig. 7 Models

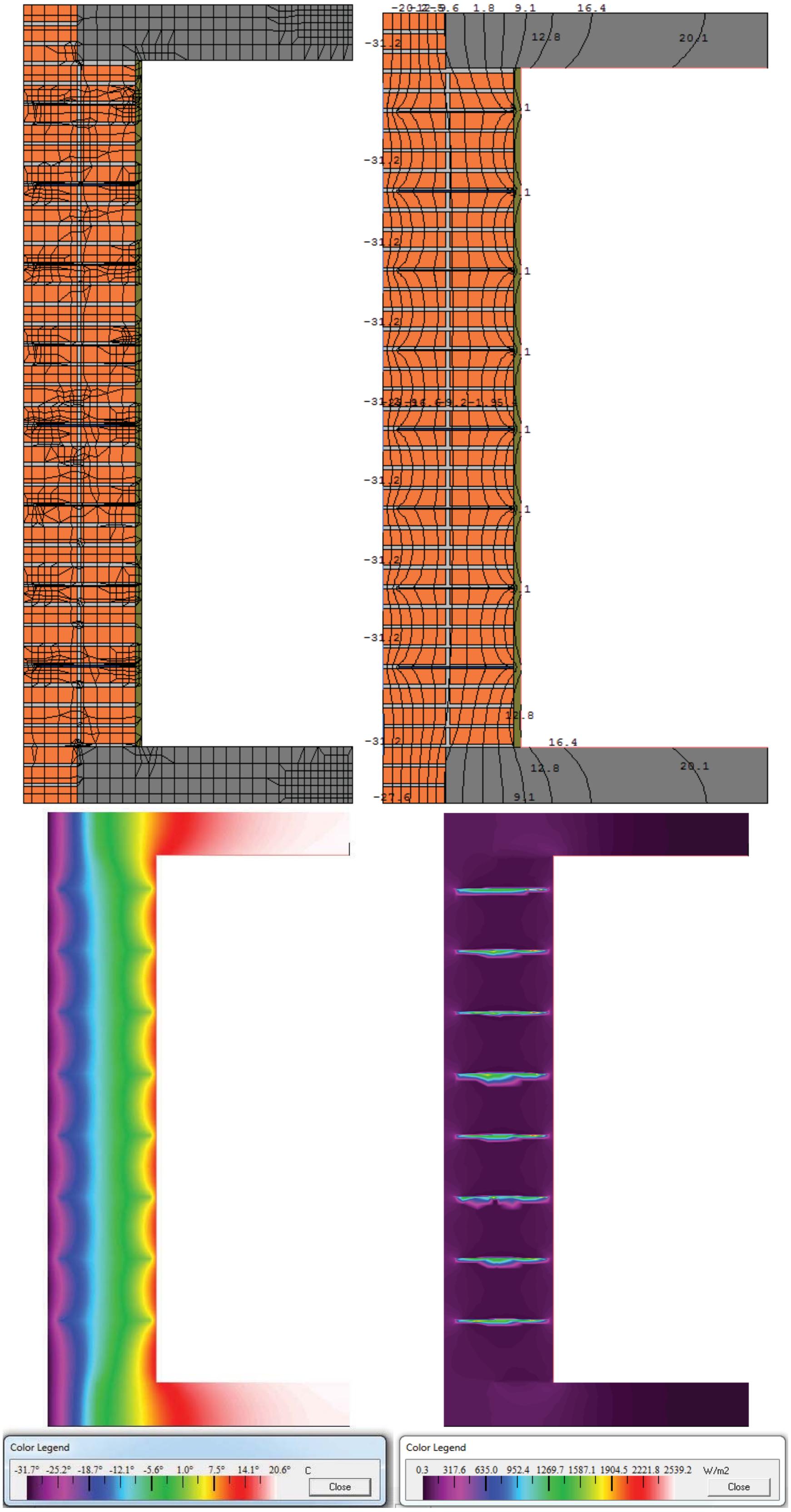

Fig. 8 Simulation results of the conventional wall

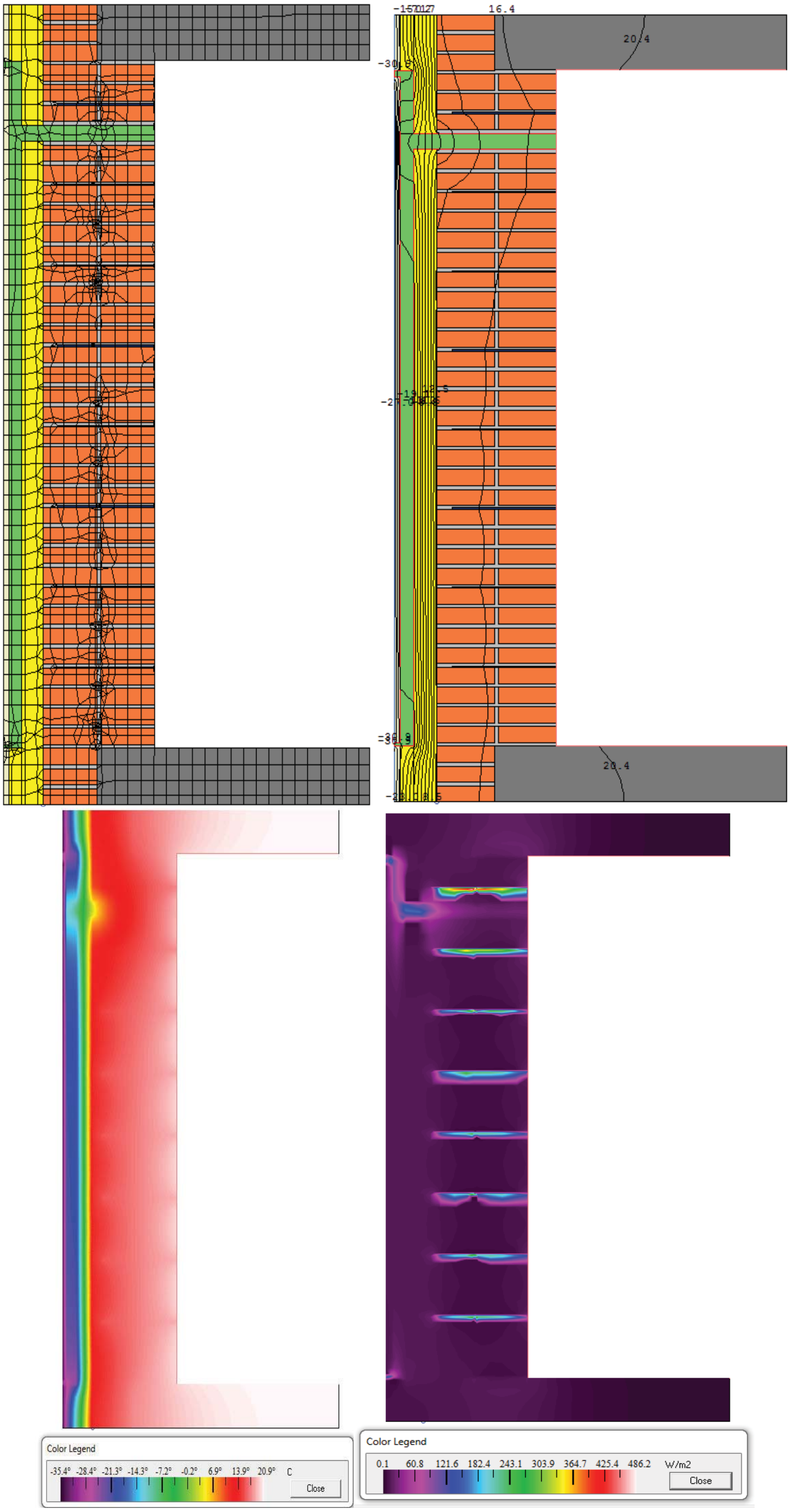

Fig. 9 Simulation results of the proposed solution

Place of construction is Astana. Heating degree days 6256, normalized calculated thermal resistance of the ventilated air layer is taken equal to R≈1.0 $m^2·°C/W$ [10].

Table II represents the initial and proposed solution for the envelopes. The first option is the values of the usual soviet building; the second option is the proposed one.

B. Simulation Results of the Conventional Walls

Simulation results of exterior walls are shown in Fig. 8 in the form of a finite-element mesh, isotherm, the vectors, line of the heat flux, the temperature gradients, color lines of heat flux, heat transfer coefficient and the thermal resistance.

Conventional thermal resistance excluding thermal inhomogeneity (reinforcing communication), R_0=1.0 $m^2·°C/W$. The heat transfer coefficient U = 1.58 $W/m^2·°C$

The heat transfer resistance R^r = 0.63 $W/m^2·°C$, which is 6 times less than the required value R^{req} = 3.6 $m^2·°C/W$ [17].

During the summer non-insulated walls are heated to high temperatures, creating unbearable conditions in the premises for cooling indoor air conditioners are used. In winter time buildings with such envelope tend to lose the heat quickly.

The simulation results indicate that the external wall is vulnerable to outside conditions, the dew point temperature lies inside the wall and the construction is exposed to the frost that consequently leads to structural failure, as well as mold formation.

TABLE II
CHARACTERISTICS OF THE ENVELOPES

Material type	Thickness, mm	Density, kg/m^3	Thermal conductivity, W/(m·C)
1st variant (Khrushchev construction)			
Solid clay brick	510	1600	0.58
Lim-sand mortar	30	1600	0.7
2nd variant			
Solid clay brick	510	1600	0.58
Lim-sand mortar	30	1600	0.7
Insulation layer	100	70	0.038
Ventilated air layer			
Façade insulating panel	25	50	0.033

C. Simulation Results of the Proposed Solution

The thermal transmittance coefficient U = 0.29 $W/m^2·°C$. Thermal resistance coefficient R_0 = 3,5$m^2·°C/W$ (ignoring fastening elements).

Analysis of the simulation shows that the inlet air temperature at the bottom layer was τ_1 = -25.3 °C, at the level of the additional supply channel τ_2 = -11.3 °C, and the temperature of the air entering the room was τ_3 = 18.6 °C (see. Fig. 9). The air in the layer from its bottom to top warmed up to $\Delta\tau = \tau_2 - \tau_1$ = 14.1 °C. Full heating of the air entering the room from the entrance to the exit of the design was $\Delta\tau_{kon} = \tau_3 - \tau_1$ = 43.9 °C, i.e. increasing the number of the outgoing transmission of heat back into the room as warm air for ventilation. At the same time, the supply channel thermal transmittance coefficient reached U = 0,37 $W/m^2·°C$, and the thermal resistance R_0 = 2.67 $m^2·°C/W$.

To fix the amount of light screens, brackets and anchors can be reduced, which leads to an increase in heat engineering uniformity coefficient r and the heat-shielding qualities fence R. In addition, reduces the load on the load-bearing walls and foundation of the building and increases the service life of the building.

V. DISCUSSION AND CONCLUSION

The study examines the current construction trends and energy efficiency option in construction sector in the Republic of Kazakhstan. According to the results of the energy survey issued a report containing information about the energy efficiency class and recommendations on measures to reduce the energy consumption of the building, as well as presented the technical justification and calculation of the economic feasibility of their application, which will allow the building owner to carry out energy conservation measures with regard to their effectiveness and payback periods. To meet the requirements of thermal protection of the buildings and indoor comfort it has been proposed to use the organized air exchange through the external walls of old housing stock in the country. The simulation has been conducted on conventional wall with the average U=1 $W/m^2·°C$, and proposed wall solution consisting of additional insulation and the screens. The demonstrated efficacy of light insulated materials as protective and decorative screen (outer cladding) in exterior walls with ventilated layers for the purpose of ventilating the room compared to traditional heavy screen in the case of a minor transformation with the installation of additional ventilation equipment. The results showed the positive effect of the proposed solution and is recommended for further use. The advantage of this method is as saving the energy spent on heating and ventilation of buildings through the use of the outgoing (transmission) of natural heat and warm air in the room, so the improving moisture conditions of exterior walls.

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