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RESEARCH ARTICLE

THE INFLUENCE OF THE FEATURES OF THE CONSTRUCTIVE SOLUTIONS OF THE CONSTRUCTION OF THE WALL ON ITS HEAT-TECHNICAL CHARACTERISTICS

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Abstract. *The study addresses the relevance of improving the thermal performance of wall structures as one of the key factors in enhancing the energy efficiency and sustainability of buildings. Modern construction increasingly requires materials and design solutions that minimize heat loss while maintaining structural strength and indoor comfort. To achieve this, the research analyzes wall models composed of gypsum plaster, ceramic brick, cement-sand mortar, and ceramic tiles with the inclusion of a mineral wool insulation layer. The methodology combines experimental data with mathematical modeling performed in the ELCUT software, allowing the evaluation of heat transfer resistance, temperature distribution, and condensation risk in multilayer wall systems. Two insulation placement options—internal and external—were compared in terms of their impact on the thermal resistance and overall temperature profile of the structure. The analysis demonstrates that the external arrangement of insulation provides higher thermal stability, reduces the risk of cracking and moisture accumulation, and ensures better preservation of internal heat. Conversely, internal insulation may lead to temperature gradients that decrease material durability and comfort conditions. The obtained results confirm the necessity of optimizing the location of thermal insulation in wall constructions to achieve an optimal balance between energy efficiency and mechanical performance. The conclusions of the study are valuable for engineers and architects developing modern, cost-effective, and environmentally sustainable building envelopes.*

Keywords: *thermal performance, thermal insulation, thermal conductivity of materials, wall structures, thermal resistance.*

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ҒЫЛЫМИ МАҚАЛА

ҚАБЫРҒАЛЫҚ КОНСТРУКЦИЯНЫҢ ҚҰРЫЛЫМДЫҚ ШЕШІМДЕРІНІҢ СИПАТТАМАЛАРЫНЫҢ ОНЫҢ ЖЫЛУЛЫҚ КӨРСЕТКІШТЕРІНЕ ӘСЕРІ

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Аңдатпа. *Зерттеу жұмысының өзектілігі ғимараттардың энергия тиімділігін арттыру және қоршау конструкциялары арқылы болатын жылу жоғалтуларды азайту қажеттілігімен негізделеді. Қазіргі құрылыс саласында материалдардың беріктігі мен ұзақ мерзімділігін сақтай отырып, жоғары жылулық қорғаныс деңгейін қамтамасыз ететін оңтайлы конструктивтік шешімдерді табу маңызды міндеттердің бірі болып табылады. Бұл жұмыста гипс сылақ, керамикалық кірпіш, цемент-құм ерітіндісі және қаптама плиткадан тұратын, минералды жүн қабатымен толықтырылған қабырғалық құрылым қарастырылды. Зерттеу әдістемесі ELCUT бағдарламалық кешенін пайдалану арқылы жылу процестерін математикалық модельдеуге негізделген. Бұл тәсіл жылу өткізгіштікке қарсы кедергісін, температураның таралуын және көпқабатты жүйеде ылғалдың конденсациялану қаупін талдауға мүмкіндік берді. Талдау барысында жылу оқшаулау қабатының ішкі және сыртқы орналасуының екі нұсқасы салыстырылды. Нәтижелер сыртқы жылу оқшаулау нұсқасының тиімдірек екенін көрсетті, себебі ол температураның біркелкі таралуын қамтамасыз етіп, құрылымдық деформация мен сыртқы орта әсеріне төзімділікті арттырады. Ал ішкі оқшаулау, керісінше, несущи элементтердің салқындауына және беріктіктің төмендеуіне әкелуі мүмкін. Зерттеу нәтижелері жылутехникалық және пайдалану сипаттамаларын ескеретін кешенді жобалау тәсілінің қажеттілігін дәлелдейді. Алынған мәліметтер энергия тиімді және экологиялық тұрғыдан тұрақты ғимараттарды жобалауда қолдануға болады.*

Түйін сөздер*: жылу өнімділігі көрсеткіштері, жылу оқшаулаулағыш, жылуөткізгіштік, қабырғалық құрылымдар, жылу кедергісі.*

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НАУЧНАЯ СТАТЬЯ

ВЛИЯНИЕ ОСОБЕННОСТЕЙ КОНСТРУКТИВНЫХ РЕШЕНИЙ КОНСТРУКЦИИ СТЕНЫ НА ЕЕ ТЕПЛОТЕХНИЧЕСКИЕ ХАРАКТЕРИСТИКИ

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Аннотация. *Актуальность исследования обусловлена необходимостью повышения энергоэффективности зданий и сокращения теплопотерь через ограждающие конструкции. Современные требования строительной отрасли направлены на поиск оптимальных конструктивных решений, обеспечивающих высокий уровень теплозащиты при сохранении прочности и долговечности материалов. В работе рассмотрена стеновая конструкция, включающая гипсовую штукатурку, керамический кирпич, цементно-песчаный раствор и облицовочную плитку, дополненная слоем теплоизоляционного материала — минеральной ваты. Методика исследования основана на математическом моделировании тепловых процессов с использованием программного комплекса ELCUT, что позволило проанализировать сопротивление теплопередаче, распределение температур и риск конденсации влаги в многослойной системе. Проведено сравнение двух вариантов расположения теплоизоляционного слоя — внутреннего и наружного — с точки зрения их влияния на термическую устойчивость и эксплуатационные свойства конструкции. Результаты показали, что наружное размещение теплоизоляции обеспечивает более равномерное распределение температуры, уменьшает тепловые деформации и повышает устойчивость к воздействию внешней среды. Внутреннее расположение, напротив, способствует переохлаждению несущих элементов и снижению долговечности. Сделаны выводы о необходимости комплексного подхода к проектированию стеновых конструкций с учетом теплотехнических и эксплуатационных характеристик. Полученные данные могут быть использованы при разработке энергоэффективных и экологически устойчивых зданий.*

Ключевые слова: *теплотехнические показатели, теплоизоляция, теплопроводность, стеновые конструкции, тепловое сопротивление.*

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CONFLICT OF INTEREST

The authors state that there is no conflict of interest.

During the preparation of this manuscript, the authors used artificial intelligence tools (ChatGPT) solely for editorial assistance, such as improving phrasing and checking grammar, spelling, and punctuation. All ideas, interpretations, and conclusions are the responsibility of the authors, who take full accountability for the content of the article.

АЛҒЫС / ҚАРЖЫЛАНДЫРУ КӨЗІ

Зерттеу жеке қаржыландыру көздерін пайдалана отырып жүргізілді.

МҮДДЕЛЕР ҚАҚТЫҒЫСЫ

Авторлар мүдделер қақтығысы жоқ деп мәлімдейді.

Мақаланы дайындау барысында авторлар жасанды интеллект құралдарын (ChatGPT) тек редакциялық көмек мақсатында пайдаланды: тұжырымдарды жетілдіру, грамматикалық, орфографиялық және тыныс белгілеріндегі қателерді тексеру үшін. Барлық идеялар, интерпретациялар мен қорытындылар авторларға тиесілі, және олар мақаланың мазмұнына толық жауапты.

БЛАГОДАРНОСТИ/ИСТОЧНИК ФИНАНСИРОВАНИЯ

Исследование проводилось с использованием частных источников финансирования.

КОНФЛИКТ ИНТЕРЕСОВ

Авторы заявляют, что конфликта интересов нет.

При подготовке рукописи авторы использовали инструменты искусственного интеллекта (ChatGPT) исключительно для редакторской поддержки: корректировки формулировок, проверки грамматических, орфографических и пунктуационных ошибок. Все идеи, интерпретации и выводы принадлежат авторам, которые несут полную ответственность за содержание статьи

1 INTRODUCTION

Modern construction places high demands on the energy efficiency of buildings, which is associated with the need to reduce heating costs, reduce operating costs, and improve the environmental performance of construction projects. One of the main factors determining the thermal performance of buildings is the design solutions of wall structures. These structures not only function as an enclosing element, but are also active participants in the heat exchange processes between the internal and external spaces.

Thermal performance of walls depends on many factors, including the properties of materials, the order of their arrangement in the layer, the presence and location of thermal insulation, as well as important quality indicators. The most important indicators are the overall resistance to heat transfer and the ability of the structure to prevent the formation of cold bridges and condensation. Incorrect design or incorrect choice of materials can lead to significant heat loss, increased energy consumption and deterioration in the performance of the building, including a decrease in its durability and suitability for habitation. Since it is necessary to solve the problem of reducing both heating costs and the costs of subsequent major repairs of buildings, it is necessary to know about the durability of the materials used, the physical and mechanical properties of which can change significantly under operating conditions (**Kuznetsova & Mammadov, 2024**).

Particular attention is paid to the location of the thermal insulation layer in the wall structure, since it is this factor that significantly affects the thermal protection of the building (**Mukhamejanova et al., 2025**).

2 LITERATURE REVIEW

In recent decades, the construction industry has seen a steady trend towards improving the energy efficiency of buildings. According to **GOST 30494-2011**, one of the most important factors affecting the energy consumption of buildings is the thermal resistance of enclosing structures, in particular walls (**Kuanyshbai & Aubakirova, 2024**). Walls are a key element determining the level of heat loss, and their design solutions require careful selection and analysis.

According to experts, optimizing the thermal characteristics of enclosing structures can reduce the energy consumption of buildings by up to 30% (**Karamanos & Bakolas, 2020**). This is especially important in countries with cold climates, where heating accounts for 60% of total energy consumption.

Main research areas:

- Thermal conductivity of building materials is one of the key parameters influencing thermal performance. For example, research by the Laboratory of Construction Technologies has shown that the use of cellular concrete, foam blocks and multilayer structures with thermal insulation layers can significantly improve the thermal performance of walls (**Romanovskiy, 2023**).

- Based on the characteristics of multilayer structures, multilayer walls consisting of a load-bearing layer, thermal insulation material and finishing have high thermal resistance. For example, the use of mineral wool and expanded polystyrene as insulation can reduce heat loss by up to 40% (**Dileep Kumar, 2020**).

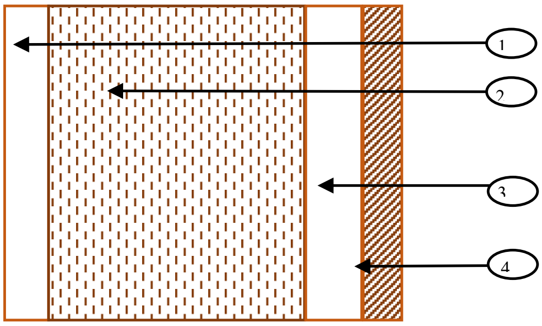
- The influence of structural elements In addition to the main material, structural elements play an important role: supports, joints and corners. Poorly executed structural elements often create "thermal bridges", which leads to significant heat loss (**Dobrosmyslov et al., 2021**).

- From an environmental perspective, modern building materials should not only be energy efficient, but also environmentally friendly. For example, studies have shown that the use of natural materials, such as wood panels insulated with flax, reduces the carbon footprint of a building (**Grazhdankin et al., 2020**).

3 MATERIALS AND METHODS

The object of analysis is the wall structure of a residential building, consisting of alternating layers of materials, each of which performs a specific function and has unique technical characteristics, such as thickness and thermal conductivity.

Figure 1 shows the main components (layers) of the wall structure:



1 – internal surface: gypsum plaster

2 – load-bearing part: solid ceramic brick

3 – binder: cement-sand mortar

4 – outer surface: ceramic tile

Figure 1 – Structural elements of the analysis object (author's material)

A design solution was proposed that included adding an additional section of thermal insulation to improve the energy efficiency of the structure. It is recommended to use mineral (basalt) wool as insulation (**Szostak & Golewski , 2020**). To conduct the analysis, the following main stages are consistently performed: creating structural elements to create a mathematical model based on the initial data and calculated characteristics of the wall structure (**Tukhtamisheva & Adilova, 2025**); studying the effect of the location of the thermal insulation layer in the wall structure on its thermal properties; analyzing the effect of the thickness and thermal conductivity parameters of the structural layers on thermal characteristics.

The initial data and calculated characteristics of the mathematical model of the wall structure are given in **Tables 1 and 2**.

Table 1

General data of the mathematical model of the wall structure

№	Name of quality indicators of calculated characteristics	Marking/ expression	Meaning	Unit of measure
1	General source data			
1.1	Number of layers in the resulting structure (including the layer of thermal insulation material)	S	5	Unity
1.2	Number of types of building materials used in wall structures	E	5	Unity
1.3	The optimal air temperature in the living room during the cold season is the internal temperature	t	20	°C
1.4	Estimated outside temperature - ambient temperature	t	-26	°C
2	Layer thickness			
2.1	Gypsum plaster	$\delta_{\varepsilon=1}$	0,005	M
2.2	Ceramic solid brick	$\delta_{\varepsilon=1}$	0,51	M
2.3	Cement-sand mortar	$\delta_{\varepsilon=1}$	0,01	M
2.4	Ceramic tiles	$\delta_{\varepsilon=1}$	0,01	M
3	Density			
3.1	Gypsum plaster	$\rho_{\varepsilon=1}$	1200	kg/m^3
3.2	Ceramic solid brick	$\rho_{\varepsilon=2}$	1900	kg/m^3
3.3	Cement-sand mortar	$\rho_{\varepsilon=3}$	1800	kg/m^3
3.4	Ceramic tiles	$\rho_{\varepsilon=4}$	2000	kg/m^3
4	Thermal conductivity			
4.1	Gypsum plaster	$\lambda_{\varepsilon=1}$	0,3	$Watt/m^2 \cdot {}^\circ C$
4.2	Ceramic solid brick	$\lambda_{\varepsilon=2}$	0,72	$Watt/m^2 \cdot {}^\circ C$
4.3	Cement-sand mortar	$\lambda_{\varepsilon=3}$	0,93	$Watt/m^2 \cdot {}^\circ C$
4.4	Ceramic tiles	$\lambda_{\varepsilon=4}$	1,05	$Watt/m^2 \cdot {}^\circ C$
4.5	Thermal insulation material	$\lambda_{\varepsilon=5}$	0,04	$Watt/m^2 \cdot {}^\circ C$

Continuation of Table 1

Note: * The value of the source data element 2.1 – 2.4 is determined by: 1. GOST 530-2012 “Ceramic brick. Technical conditions”; 2. GOST 31358-2007 “Finishing materials. Ceramic tiles for walls”; 3. SNiP (Construction Norms and Rules) 23-02-2003 “Thermal protection of buildings”. * The value of the source data element 3.1 – 3.4 is determined by: 1. GOST R 57957-2017 “Gypsum binders and plaster. Definitions and requirements”; 2. GOST 530-2012 “Ceramic brick. Technical conditions”; 3. GOST 28013-2023 “Building mortars. General technical conditions”; 4. GOST 31358-2007 “Finishing materials. Ceramic tiles for walls”. * The value of the source data element 4.1 – 4.4 is determined by: 1. SP (Sanitary Rules and Regulations) 50.13330.2012 "Building climatology. Design standards for thermal characteristics"; 2. GOST 530-2012 "Ceramic brick. Technical conditions"; 3. SP (Sanitary Rules and Regulations) 60.13330.2016 RF "Design of buildings and structures. Thermal calculations"; 4. GOST 31358-2007 "Finishing materials. Ceramic tiles for walls".

Table 2

Calculation characteristics of the mathematical model of the wall structure

№	Name of the constructive characteristic	Marking/ expression	Meaning	Unit of measure
1	Basic design characteristics			
1.1	Thermal resistance			
1.1.1	Gypsum plaster	$R_{\varepsilon=1} = \delta_{\varepsilon=1}/\lambda_{\varepsilon=1}$	0,1667	$(m^2 \cdot °C)/Watt$
1.1.2	Ceramic solid brick	$R_{\varepsilon=1} = \delta_{\varepsilon=1}/\lambda_{\varepsilon=1}$	0,7083	$(m^2 \cdot °C)/Watt$
1.1.3	Cement-sand mortar	$R_{\varepsilon=1} = \delta_{\varepsilon=1}/\lambda_{\varepsilon=1}$	0,0215	$(m^2 \cdot °C)/Watt$
1.1.4	Ceramic tiles	$R_{\varepsilon=1} = \delta_{\varepsilon=1}/\lambda_{\varepsilon=1}$	0,25	$(m^2 \cdot °C)/Watt$
1.2	General project characteristics			
1.2.1	Duration of the heating period	$D_d = (t_{int} - t_{ext}) \cdot z_{ht}$	4796	$°C \cdot day$
1.2.2	Standard value of thermal resistance of a wall structure	$R_{req} = a \cdot D_d + b$	3,0786	$(m^2 \cdot °C)/Watt$
1.2.3	Thermal resistance of the inner surface of the wall structure	$R_{in} = \frac{1}{a_{in}}$	0,1149	$(m^2 \cdot °C)/Watt$
1.2.4	Thermal resistance of the outer part of the floor	$R_{out} = R_{in} + R_{\varepsilon}$	Various	$(m^2 \cdot °C)/Watt$
1.2.5	Average value of thermal resistance in the floor	$\overline{R}_s = \frac{R_{in} + R_{out}}{2}$	Various	$(m^2 \cdot °C)/Watt$
1.2.6	Temperature of the inner part of the floor	$\tau_{in} = t_{out} - \frac{t_{in} - t_{out}}{R} \cdot k_m \cdot R_{in}$	Various	°C
1.2.7	Temperature of the outer part of the floor	$\tau_{out} = t_{in} - \frac{t_{in} - t_{out}}{R} \cdot k_m \cdot R_{in}$	Various	°C
1.2.8	Average value of the floor temperature	$\tau_{avg} = t_{in} - \frac{t_{in} - t_{out}}{R} \cdot k_m \cdot \overline{R}$	Various	°C

Note:
*The value of input data elements 1.1.1 – 1.1.4 is determined in accordance with: SP (Sanitary Rules and Regulations) 50.13330.2012 “Building climatology. Standards for design of thermal characteristics”
*The calculation of design characteristics is carried out in accordance with SNiP (Construction Norms and Rules) 23-02-2003 “Thermal protection of buildings”;

4 RESULTS AND DISCUSSION

In the next stage, an analysis was carried out of the influence of the location of the layer of thermal insulation material in the general sequence of layers of the wall structure (as an element determining, among others, its strength and reliability). On its thermal characteristics (**Egorochkina, 2021**). The analysis is based on the following main points.

1. The location of the insulation in the building envelope is selected taking into account the functional purpose and operating conditions of buildings and premises.

2. The adopted design solution (within the framework of improving the energy efficiency of the wall structure) should ensure the necessary thermal stability of the internal microclimate of the premises with minimal energy consumption for heating and air conditioning (**Zhangabay et al., 2025**).

The design solution should ensure the absence of condensation and freezing in the layers of the enclosing structure, as well as minimize thermal deformation of these layers caused by fluctuations in outside air temperature and other climatic factors affecting the operation of the structure during construction (**Karpov & Pavlov, 2020**). Based on these rules, two alternative options for placing a mineral wool layer in the wall structure are proposed:

1. Placing mineral wool between the inner surface (gypsum plaster) and the load-bearing part (ceramic solid brick).

2. Placing mineral wool between the load-bearing part (ceramic solid brick) and the connecting part (cement-sand mortar).

The most suitable option for placing thermal insulation material in the general sequence of layers of the wall structure (**Xin-Kai Hao et al., 2021**) is schematically presented in **Figure 2.**

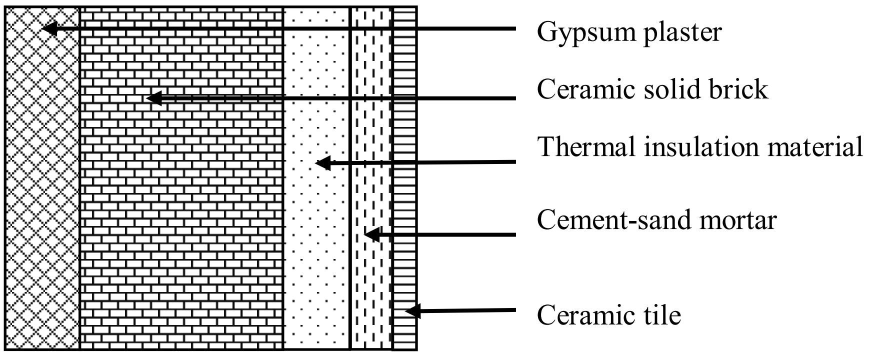


Figure 2 - The most suitable option for placing thermal insulation material in the general sequence of layers of the wall structure (author's material)

The "important" quality indicators for this structure are determined by the following formulas from SNiP (Construction Norms and Rules) 23-02-2003:

The total indicator of the thickness of the boundary surface is calculated using the **Formula 1**:

$$\Delta_{equ} = \lambda_{eff} \cdot R_{total} \tag{1}$$

where: λ_{eff} - effective thermal conductivity of the structure.

The boundary surface temperature $T_{b.p.}$ is determined by **Formula 2**:

$$T_{b.p.} = T_{in} - (T_{in} - T_{out}) \cdot R_{in}/R_{total} \tag{2}$$

where: T_{in} - internal air temperature (°C);

T_{out} - external air temperature (°C);

R_{in} - internal surface heat transfer resistance ($m^2 \cdot$ K/Watt);

R_{total} - total thermal resistance of the entire structure ($m^2 \cdot$ K/Watt).

A description of the corresponding source data and variable construct characteristics is provided in **Table 3**.

Table 3
Characteristics at the boundaries of layers and points in the temperature versus wall thickness graph (author's material)

Calculation options	1 version		2 version	
Carrier/layer interface index	Total indicator of the thickness of the boundary surface	Boundary surface temperature	Total indicator of the thickness of the boundary surface	Boundary surface temperature
s'	$\Delta_{s'}$	$\tau_{s'}$	$\Delta_{s'}$	$\tau_{s'}$
-	m	°C	m	°C
1	0,00	18,3	0,00	18,3
2	0,01	18,1	0,01	18,0
3	0,07	-14,1	0,50	7,7
4	0,59	-24,7	0,59	-24,7
5	0,61	-25,2	0,61	-25,3
6	0,62	-25,4	0,63	-25,3
Opportunity point index	Total thickness of the wall structure	Average temperature value of the wall structure cross section	Total thickness of the wall structure	Average temperature value of the wall structure cross section
ν	Δ_{ν}	τ_{ν}	Δ_{ν}	τ_{ν}
-	m	°C	m	°C
1	0	18,1	0	18,2
2	0,01	18,1	0,1	18,2
3	0,01	1,9	0,1	12,6
4	0,08	1,9	0,53	12,6
5	0,08	-19,4	0,53	-8,8
6	0,60	-19,4	0,60	-8,8
7	0,60	-25,1	0,60	-25,1
8	0,63	-25,1	0,63	-25,1
9	0,61	-25,4	0,63	-25,4
10	0,62	-25,3	0,62	-25,4

A graphical representation of these results in terms of temperature distribution across the thickness (**Pomada, 2024**) of the wall structure is presented in **Figure 3**.

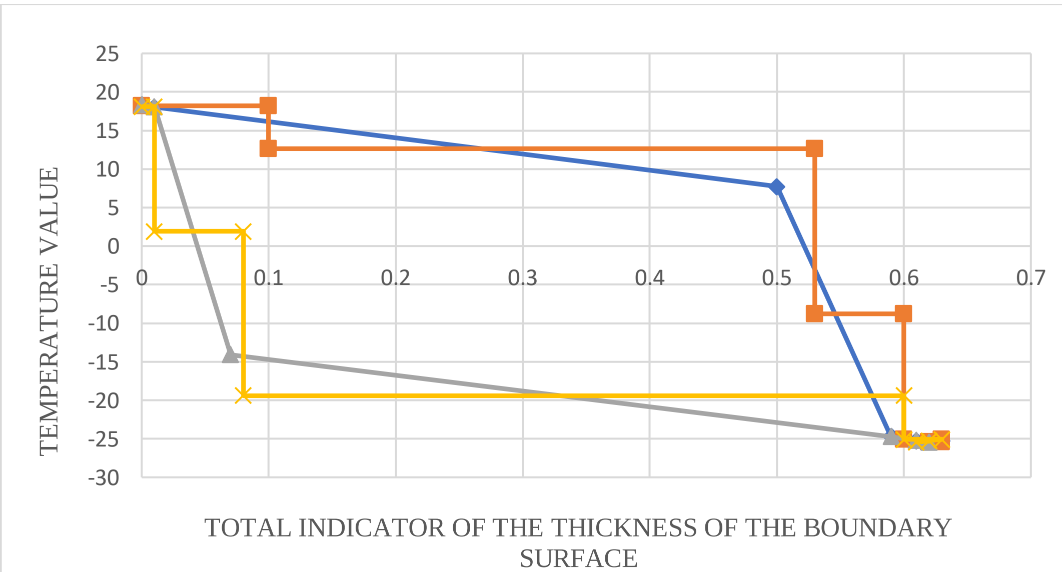


Figure 3 - Graphs of the dependence of the average temperature in the cross section of the wall structure on the total indicator of its thickness in the context of the considered calculation options (author's material)

As a result of the analysis based on graphs, it was found that the technical characteristics of the layers (thickness and thermal conductivity) significantly affect the weighted average temperature depending on their location in the wall structure, while maintaining a constant level of thermal resistance (**Rodionov, 2020**). Placing mineral wool between the load-bearing and connecting layers (option 2) is more preferable (**Zhapakhova & Uderbayev, 2024**), since it provides a positive average temperature, maintains the stability of the wall and prevents the formation of cracks due to temperature deformations (**Biks et al., 2022**). On the contrary, placing mineral wool between the internal and load-bearing layers (option 1) can increase temperature differences and lead to deformation, reduced energy efficiency and deterioration of structural reliability (**Marushchak & Pozniak, 2022**).

Based on the data obtained (**Palani et al., 2023**), a mathematical model of the influence of design solutions on heat-saving parameters was built in the ELCUT software product (**Figure 4**).

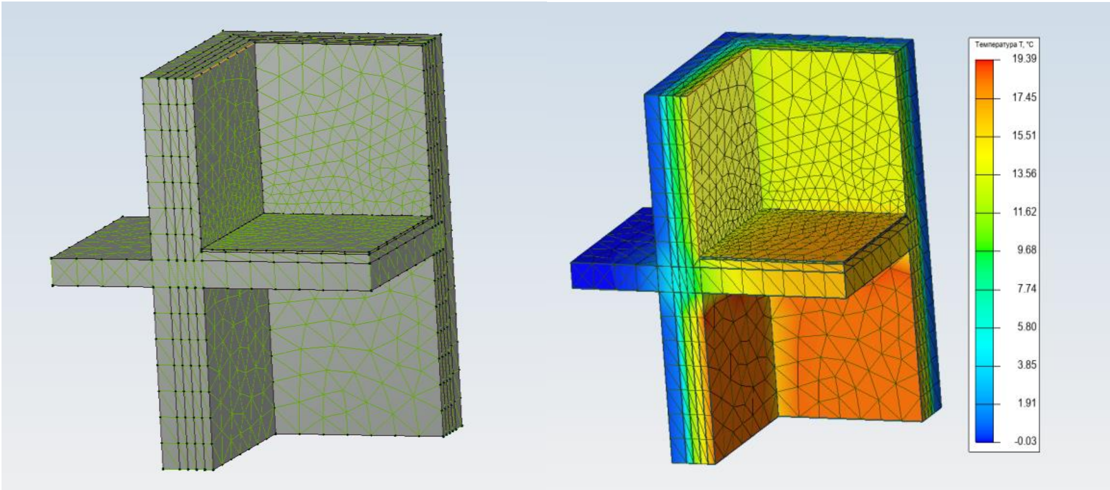


Figure 4 - Temperature distribution in the calculation area (author's material)

5 CONCLUSIONS

The location of the thermal insulation layer in a wall structure consisting of gypsum plaster, solid brick, cement-concrete mortar and ceramic tiles significantly affects its thermal properties and strength. During the study, an assessment was carried out to determine the influence of structural solutions and layer parameters of the wall construction on its thermal performance. Calculations showed that the location of the thermal insulation layer significantly changes the temperature distribution across the wall thickness, while the overall thermal resistance remains constant (approximately 3.07 $m^2 \cdot °C/Watt$).

1. When the mineral wool layer is placed externally, between the ceramic brick and the cement–sand mortar, the average temperature across the wall section remains within the range of +1.9 to +10 °C, which ensures a stable thermal regime and prevents moisture condensation.

2. With internal placement of the insulation (between the gypsum plaster and the brick), the temperature drops to –12 to –18 °C, leading to cooling of the load-bearing elements and possible cracking.

3. Thus, external insulation is the most rational solution, as it allows reducing building heat loss by 15–20%, extending the service life of enclosing structures, and improving indoor comfort conditions.

4. To further enhance energy efficiency, it is recommended to use materials with a thermal conductivity coefficient not exceeding 0.04 Watt/(m·K) and to ensure proper vapor and waterproofing layers.

The article makes recommendations for optimizing design solutions based on increasing the energy efficiency of buildings and ensuring their resistance to operational loads. The results of the study have important practical implications for designers and engineers seeking to create environmentally friendly and economical buildings.

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