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Analysis of the Power Effectiveness Class of a Building Upgraded with an Innovative Block

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Keywords: power effectiveness class, innovative block, modeling, temperature fields, heat consumption.

Abstract: One of the solutions to environmental pollution is the use of power-effective materials in the construction and modernization of buildings. Therefore, the aim of this study is to conduct a theoretical analysis in ANSYS of the thermal protection of a building using new power-effective wall blocks in cold climate conditions. The study examined four types of wall structures. The research results demonstrated that the new Porotherm 38 conventional brick structure is 1.28 times more effective in terms of thermal resistance. Similarly, the investigation of the building's thermal protection confirmed the effectiveness of the offered Porotherm 38 conventional brick design, where assisting exponents, specific characteristics, comprehensive power effectiveness values, and building power loads showed an average effectiveness improvement of 5% compared to other studied structures. The study established that the use of such wall structures can significantly enhance the overall power effectiveness class of a building. It is worth noting that the results obtained from the comprehensive study will lead to significant energy savings in buildings, and the new power-effective block design can be a valuable addition to the existing catalog of exterior power-effective wall structures.

1 INTRODUCTION

Intensifying the power effectiveness of buildings is a straightforward task that strengthens energy security, enhances environmental health, improves quality of life, and contributes to overall economic prosperity. Significant power effectiveness reserves exist worldwide, yet attempts to enhance power effectiveness often fail due to imperfect national policies or weak enforcement of relevant laws. Factors hindering success include artificially low tariffs that encourage energy overuse, subsidies for producers and consumers that distort market signals, inefficient use of housing stock, and barriers preventing new market participants. Intensifying power effectiveness remains challenging despite its numerous benefits. To achieve power effectiveness, many countries are restructuring their strategies and adopting various design solutions that contribute to economic feasibility in construction (Matic, Calzada, Eric, Babin, 2015; Michalak, 2016; Rinquet, Schwab, 2017; Nik, Mata, Kalagasidis, Scartezzini, 2016). At the national level in the Republic of Kazakhstan, various measures are also being taken to achieve power savings in one of the most prominent economic sectors – construction (Zhangabay, Abshenov, Bakhbergen, Zhakash, Moldagaliyev,

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2022; Tazhentayeva, Ahmed, 2024). Given the global context, various scientific and technical communities are developing innovative power-effective materials (Rakhimova, Zhangabay, Samoilova, Rakhimov, Kropachev, Stanevich, Karacasu, Ibraimova, 2024; Kudabayev, Mizamov, Zhangabay, Suleimenov, Kostikov, Vorontsova, Buganova, Umbitaliyev, Kalshabekova, Aldiyarov, 2022; Zhangabay, Baidilla, Tagybayev, Suleimenov, Kurganbekov, Kambarov, Kolesnikov, Ibraimbayeva, Abshenov, Volokitina, Nsanbayev, Anarbayev, 2023), products, and structures (Tagybayev, Utelbayeva, Buganova, Tolganbayev, Tulesheva, Jumabayev Kolesnikov, Kambarov, Imanaliyev, Kozlov, 2023; Zhangabay, Baidilla, Tagybayev, Sultan, 2023; Zhangabay, Kudabayev, Mizamov, Imanaliyev, Kolesnikov, Moldagaliyev, Merekeyeva, 2023), as well as implementing various standards. Approximately 40% of all extracted fuel is consumed by the construction sector, underscoring the relevance of this research area. During the operation of buildings, waste of the heat energy primarily occurs through the outer shells. For instance, in multifamily residential buildings, heat waste is distributed as follows: 20-30% through front walls, 30-40% through the ventilating system, 12-25% through windows and entry doors, 10-20% through the housetops, and 3-6% through the underground floor (Cholewa, Balaras, Nižetić, Siuta-Olcha, 2020). Therefore, enhancing the power effectiveness of outer shells, such as front walls (Zhangabay, Oner, Rakhimov, Tursunkululy, Abdikerova, 2025; Zhangabay, Tursunkululy, Utelbayeva, Abdikerova, Sultanov, 2025; Zhangabay, 2024), becomes a pressing issue. For example, in (Amani, 2025), the impact of insulation on residential buildings was studied to optimize power delivery (Malka, Kuriqi, Haxhimusa, 2022). To achieve high power effectiveness, power delivery was analyzed by selecting suitable insulation for the outer walls and housetops of residential buildings. Modeling results demonstrated that optimal insulation reduces heat waste in walls by 54.8% and in housetops by 53.5%. In (Zhang, Sun, Wang, 2022), an up-dated review of the use of phase-change materials (PCM) in outer shells was presented (Kudabayev, Mizamov, Zhangabay, Suleimenov, Kostikov, Vorontsova, Buganova, Umbitaliyev, Kalshabekova, Aldiyarov, 2022; Zhangabay, Kudabayev, Mizamov, Imanaliyev, Kolesnikov, Moldagaliyev, Merekeyeva, 2023). The main conclusion from this review is that the use of PCM in brick walls is a promising technology for reducing indoor temperature fluctuations and saving energy. Power effectiveness with PCM materials was also examined in (Kočí, Fořt, Černý, 2020), where the impact of climatic parameters was analyzed (Giyasov, Ibraimova, Tursunkululy, Kolesnikov, 2024; Tagybayev, Baidilla, Sapargaliyeva Shakeshev, Baibolov, Duissenbekov, Utelbayeva Kolesnikov, Izbassar, Kozlov, 2023; Zhangabay, Zhangabay, Utelbayeva, Tursunkululy, Sult ... 2025). In (,

The done review of modern studies indicates that achieving building power effectiveness through improved wall structure performance requires considering numerous factors that affect thermal protection and thermal stability. In nearly all studies, the primary criterion for setting initial boundary conditions is the outer climatic parameters (Zhangabay, Giyasov, Ybray, Tursunkululy, Kolesnikov, 2024; Giyasov, Bakhbergen, Tursunkululy, Kolesnikov, 2024; Zhangabay, Giyasov, Ybray, Tursunkululy, 2024; Giyasov, Ybray, Tursunkululy, 2024), which determine the type of outer wall structure. Considering that the previously mentioned studies did not evaluate the power effectiveness class in the context of outer climate conditions after modernization with an innovative material, the authors propose, as an extension of the work (Zhangabay, Bakhbergen, Aldiyarov, Tursunkululy, Kolesnikov, 2024), an analysis of the impact of outer shell structures on this parameter.

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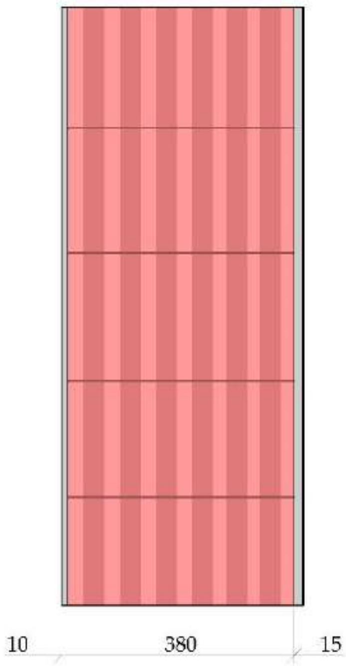
Moreover, power-effective buildings will indirectly lead to significant cost savings in construction and maintenance of facilities responsible for power supply (Ibraimova, Suleimenov, Moldagaliyev, Buganova, Jumabayev, Kolesnikov,, Tursunkululy, 2023; Zhangabay, Ibraimova, Bonopera, Suleimenov, Avramov, Chernobryvko, Utelbayeva, Uspenskiy, 2024; Zhangabay, Ibraimova, Ainabekov, Buganova, Moldagaliev, 2024; Zhangabay, Ibraimova, Tursunkululy, Buganova, Moldagaliev, Duissenbekov, 2024; Zhangabay, Ibraimova, Bonopera, Suleimenov, Avramov, Chernobryvko, Yessengali, 2024) or storage (Tursunkululy, Avramov, Chernobryvko, Suleimenov, Utelbayeva, 2022; Suleimenov, Abshenov, Utelbayeva, Imanaliyev, Mussayeva, Moldagaliyev, Yermakhanov, Raikhanova, 2022; Duissenbekov, Tokmuratov, Yerimbetov, Aldiyarov, 2020; Tursunkululy, Avramov, Chernobryvko, Kambarov, Abildabekov, Narikov, Azatkulov, 2023).

2 METHODS AND MATERIALS

2.1 Designs of Outer Facade Shells

The analysis considered 4 forms of outer facade shells. As the offered new design, an innovative facade utilizing the Porotherm 38 conventional bricks was studied, with its thermal performance compared to existing wall structures used in outer shells, including solid and hollow CER bricks with a density of 1000 kg/m³ and aerated concrete blocks with a density of 800 kg/m³. The main dimensions of the facade structures are shown in Figures 1-4, while the thermotechnical exponents of the construction materials are presented in Tables 1-4.



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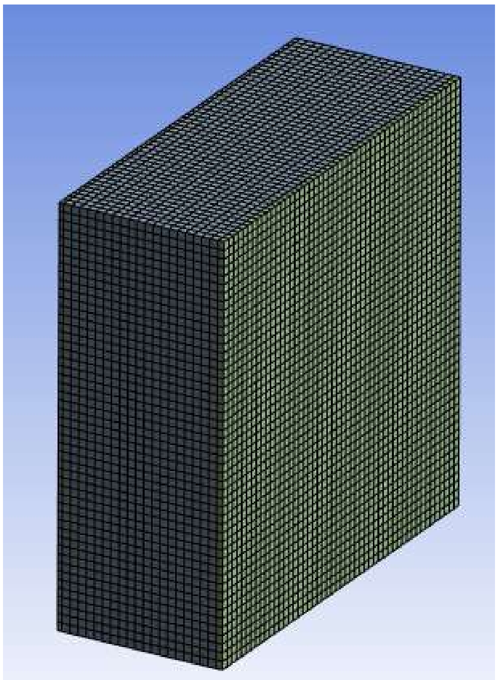

b

Figure 1: Facade Structure Utilizing the Porotherm 38 Conventional Brick (Structure 1):
a. Wall structure dimensions;
b. Finite element representation involving 52,500 hexagonal finite elements with 239,445 nodes, where the representation's medium element quality is 0.9867.

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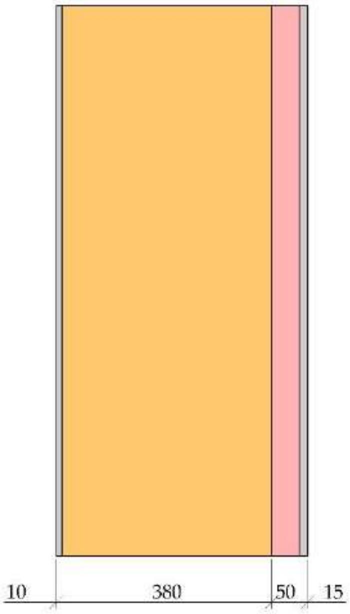

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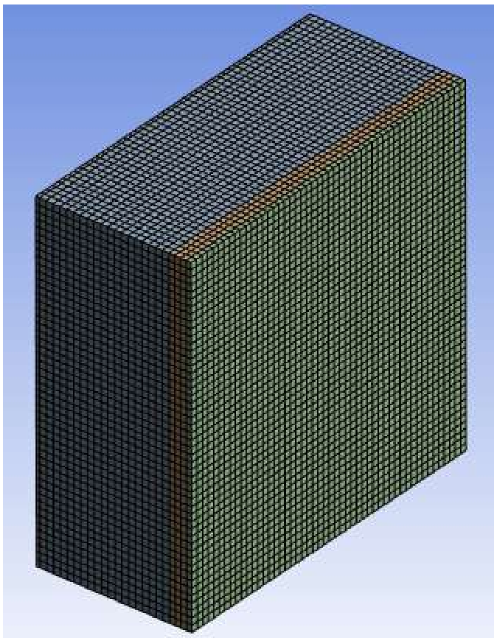
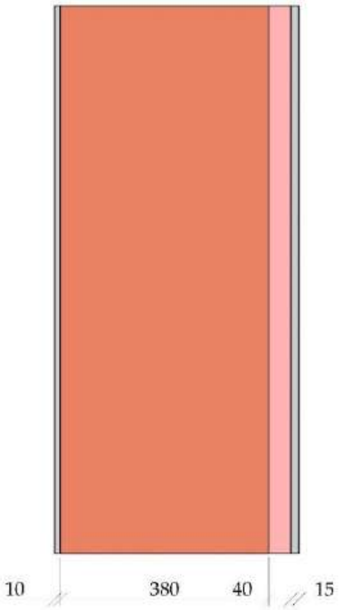


b

Figure 2: Facade Structure Utilizing the Solid CER brick (Structure 2):
a. Wall structure dimensions;
b. Finite element representation involving 60,000 hexagonal finite elements with 278,052 nodes, where the representation's medium element quality is 0.9857.



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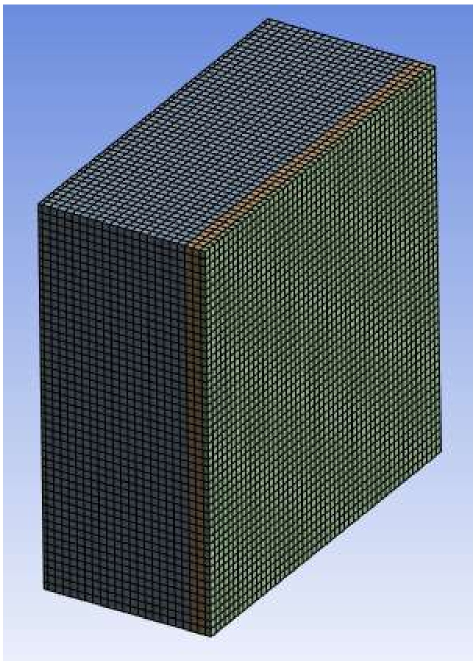

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Figure 3: Facade Structure Utilizing the Hollow CER brick with a Density of 1000 kg/m³ (Structure 3):
a. Wall structure dimensions;
b. Finite element representation involving 57,500 hexagonal finite elements with 267,750 nodes, where the representation's medium element quality is 0.9878.

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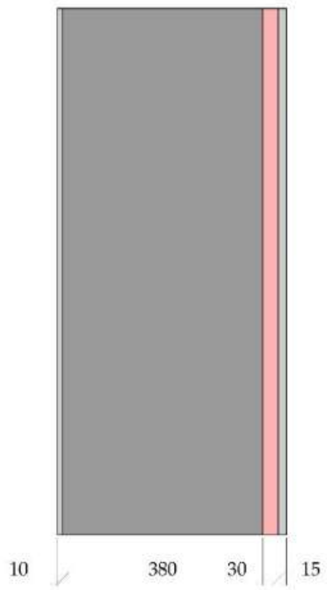

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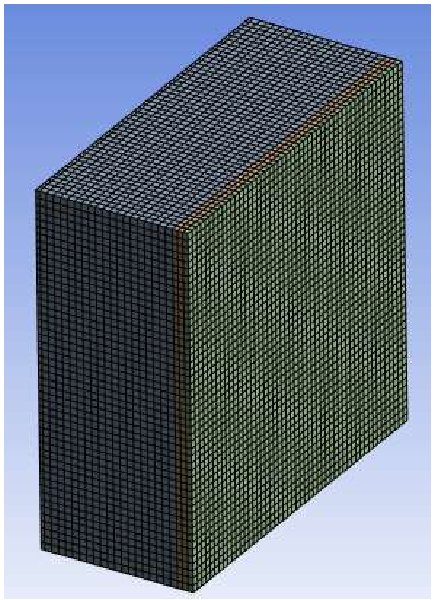

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Figure 4: Facade Structure Utilizing the Aerated Concrete Blocks with a Density of 800 kg/m^3 (Structure 4):
a. Wall structure dimensions;
b. Finite element representation involving 57,500 hexagonal finite elements with 267,750 nodes, where the representation's medium element quality is 0.9835.

Table 1: Thermotechnical Exponents of the Materials Used in the Structure Shown in Figure 1 (Zhangabay, Bakhbergen, Aldiyarov, Tursunkululy, Kolesnikov, 2024).

#	Bed Name	Heat Conductance for O & M Area A, λ, (W/(m·ºC)
1	Sand-cement matrix, 10 mm	0.76
2	Porotherm 38 conventional brick, 380 mm	0.133
3	Sand-cement matrix, 15 mm	0.76

Table 2: Thermotechnical Exponents of the Materials Used in the Structure Shown in Figure 2 (Zhangabay, Bakhbergen, Aldiyarov, Tursunkululy, Kolesnikov, 2024).

#	Bed Name	Heat Conductance for O & M Area A, λ, (W/(m·ºC)
1	Sand-cement matrix, 10 mm	0.76
2	Solid CER brick, density 1800 kg/m3, 380 mm	0.7
3	Extruded cellular polystyrene, density 35 kg/m3, 50 mm	0.029
4	Sand-cement matrix, 15 mm	0.76

Table 3: Thermotechnical Exponents of the Materials Used in the Structure Shown in Figure 3 (Zhangabay, Bakhbergen, Aldiyarov, Tursunkululy, Kolesnikov, 2024).

#	Bed Name	Heat Conductance for O & M Area A, λ, (W/(m·ºC)
1	Sand-cement matrix, 10 mm	0.76
2	Hollow CER brick, density 1000 kg/m3, 380 mm	0.47
3	Extruded cellular polystyrene, density 35 kg/m3, 40 mm	0.029
4	Sand-cement matrix, 15 mm	0.76

Table 4: Thermotechnical Exponents of the Materials Used in the Structure Shown in Figure 4 (Zhangabay, Bakhbergen, Aldiyarov, Tursunkululy, Kolesnikov, 2024).

#	Bed Name	Heat Conductance for O & M Area A, λ, (W/(m·ºC)
1	Sand-cement matrix, 10 mm	0.76
2	Aerated concrete block, density 800 kg/m3, 380 mm	0.33
3	Extruded cellular polystyrene, density 35 kg/m3, 30 mm	0.029
4	Sand-cement matrix, 15 mm	0.76

2.2 Regional Climate and Inner End Conditions

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The survey adopts the climatic variables of Shymkent, Kazakhstan (Giyasov, Ibraimova, Tursunkululy, Kolesnikov, 2024). The main climatic variables are described in Table 4.

Table 5: Climatic Variables of Shymkent (Giyasov, Ibraimova, Tursunkululy, Kolesnikov, 2024).

#	Exponents	Meanings
1	Moisture conditions in the room	Conventional
2	Moisture area	Arid
4	Application condition of building envelopes	A
3	Medium temperature of the coldest week with a probability of 0.92	–14.3 °C
4	Mid-year moisture	57%
5	Max of medium speeds by coasts in January	6.0 m/s
6	Heating period length	136 days
7	Winter inner temperature	20°C
8	Inner moisture	55%
9	Demanded resistance to heat transfer	2.25 W/m^{2}·°C

2.3 Technique to Evaluate the Heat Shield of a Residential Building Involving Examined Wall Structures

The residential building undergoing upgrading is situated in Shymkent, Kazakhstan. Its dimensions are provided in Table 6.

Table 6: Dimensions of the residential building.

Exponent	Standard Meaning	Real Meaning
Sum of the building floor surface (*A*), m^2	-	210.0
Calculated surface (public facilities) (A_1), m^2	-	-
Heated size (*V*), m^3	-	570
Overall surface area of outer building envelopes, involving (A_0), m^2:	-	536.8
1) walls (apart by form of structure), A_2	-	264.0
2) windows and balcony doors, A_3	-	28.8
3) entry doors and doorways (apart), A_4	-	4
4) garret floors, A_5	-	120.0
5) floors over crawlways or over unheated underground floors, A_6	-	120.0

The technique to calculate the building's heat shield is presented in the equations:

1. Finding the exponent of the heating degree-days

$$HDD = (t_2 - t_3)z_1 \tag{1}$$

t_2- outside temperature, °C; t_3- medium outside temperature at the time of heating, °C; z_1- heating length, d/y

2. Heat meanings of materials, climatic and geometric meanings: These meanings to be analyzed are provided in Tables 1-6.

3. Thermotechnical exponents. Finding the exponent of the reduced resistance to heat transfer of the walls: The resistance to heat transfer of the walls was found in line with in ANSYS.

4. Assisting exponents. The building's total thermal transfer rate:

$$K_1 = \frac{L}{A_1^{sum}} \sum_i \left(n_{t,i} \frac{A_{f,j}}{R_{o,j}^1} \right) \tag{2}$$

L- Volume of incoming air in the building with disordered intake or normalized meaning at controllable ventilation, m3/h; A_1^{sum}- Sum of the building floor surface (by the inner surveys of all outer shells of the building's heated envelope), m 2; $n_{t,i}$ - Coefficient that accounts for the deviation of the inside and outside temperature of the structure from the meanings used in the HDD calculation; $A_{f,j}$ - Surface area of the respective segment of the building's thermal protective envelope, m2; $R_{o,j}^1$- Reduced resistance to heat transfer of the i-th segment of the building's thermal protective envelope, m2·°C/W.

5. Specific performance. Specific heat-protective performance of the building:

$$k_1 = \frac{L}{V} \sum_i \left(n_{t,i} \frac{A_{f,i}}{R_{o,i}^1} \right) = k_1 \cdot k_2 \tag{3}$$

6. Coefficients. The standard meanings are provided in Table 9.

7. Aggregate exponents:

$$q_1^{\rho} = k_1 + k_a - \beta_1 (k_2 + k_{rad}) \tag{4}$$

k_a- Specific ventilating performance of the building, W/(m³·°C); β_1- Coefficient of reduction in air size in the building that accounts for the availability of inner building envelopes; K_{rad} - Specific performance of heat inputs to the building from solar irradiation, W/(m³·°C).

8. Power loads of the building:

$$q = 0{,}24 \cdot HDD \cdot q_1^p \cdot h$$

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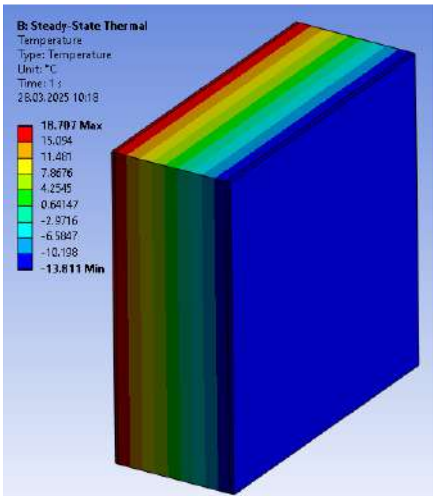
$$Q_1^y = 0{,}024 \cdot HDD \cdot V_1 q_1^{\mathrm{p}} \tag{5}$$

$$Q_2^y = 0{,}024 \cdot HDD \cdot V_1 (k_1 + k_a)$$

3 RESULTS AND DISCUSSIONS

3.1 Analysis of temperature fields

Figures 5-8 demonstrate the results of thermal field simulations for outer wall structures in ANSYS, conducted in line with the technique provided in Section 2.



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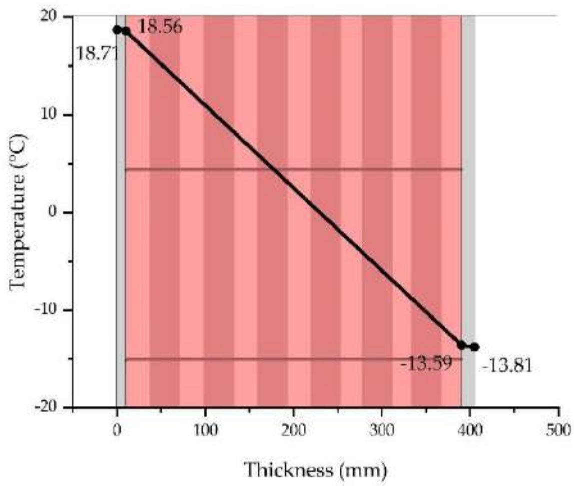

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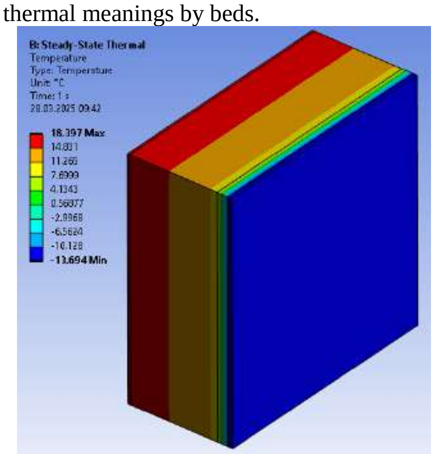
Figure 5: Thermal field in the wall structure as per Figure 1: a. Thermal field model in ANSYS; b. Curve of the wall structure's thermal meanings by beds.



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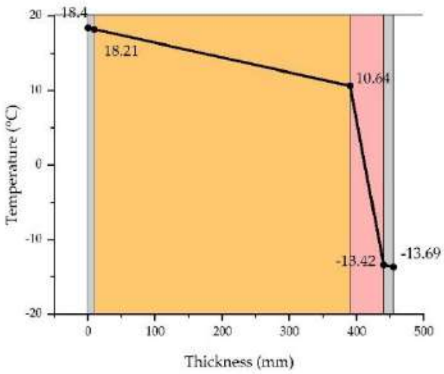

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Figure 6: Thermal field in the wall structure as per Figure 2: a. Thermal field model in ANSYS; b. Curve of the wall structure's thermal meanings by beds.

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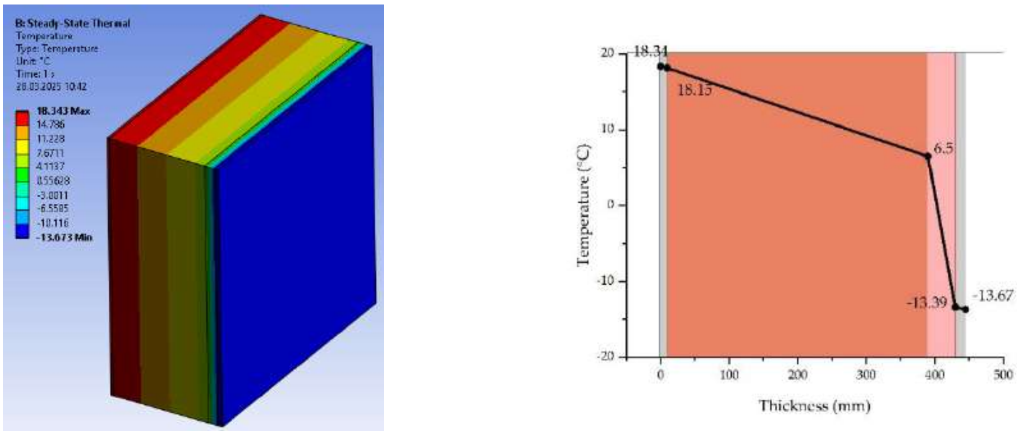
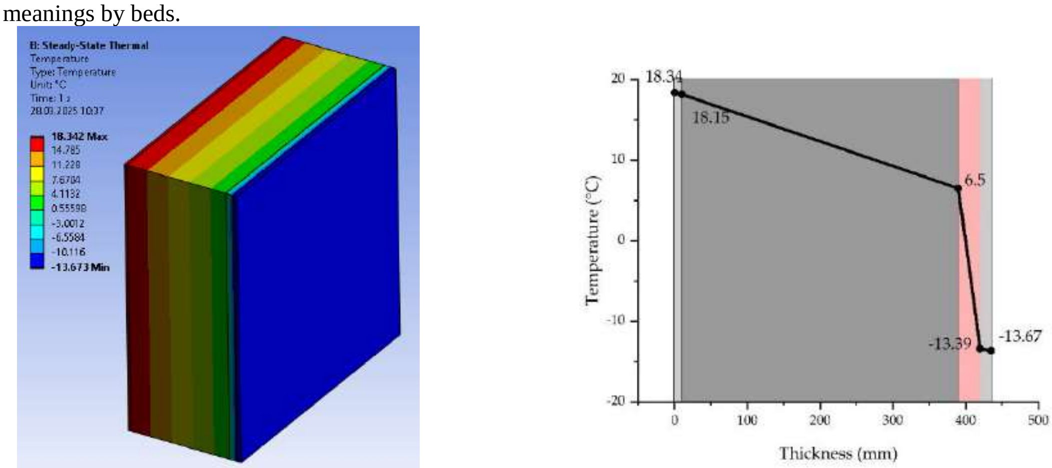


a b

Figure 7: Thermal field in the wall structure as per Figure 3: a. Thermal field model in ANSYS; b. Curve of the wall structure's thermal meanings by beds.



a b

Figure 8: Thermal field in the wall structure as per Figure 4: a. Thermal field model in ANSYS; b. Curve of the wall structure's thermal meanings by beds.

Figure 9 shows the results of the analysis of the resistance to heat transfer of the examined outer wall structures, performed in line with the calculation technique outlined in Section 2.

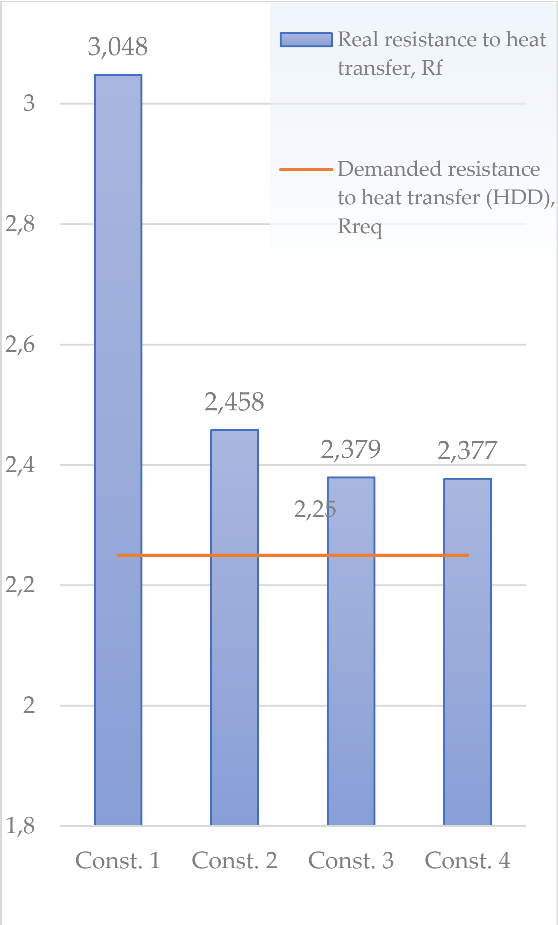


Figure 9: Resistance to heat transfer of the examined outer wall structures.

The analysis of meanings of thermal fields and resistance to heat transfer of outer wall structures shows that all constructions are in line with the demanded resistance to heat transfer of 2.25 W/m²·°C. However, at that, the offered new power-effective facade structure utilizing the Porotherm 38 conventional brick (Figure 1) demonstrates a medium effectiveness that is 1.28 times higher than that of traditional facade structures (Figure 9).

3.2 Analysis of the Heat Shield of a Residential Building Involving Examined Outer Wall Structures

The examined facade structures were assessed utilizing the calculation technique provided in Section 2. Table 7 provides the obtained and accepted meanings of the resistance to heat transfer exponent of outer facade shells, depending on its form.

Table 7: Meanings of the reduced heat shield of outer shells depending on its form.

Outer Shell Forms	Standard Meaning, m²·°C/W	Calculated Meaning, m²·°C/W (Str. 1)	Calculated Meaning, m²·°C/W (Str. 2)	Calculated Meaning, m²·°C/W (Str. 3)	Calculated Meaning, m²·°C/W (Str. 4)	Notice
Outer wall	.	.	.	.	.	Specified in line with Section 3.1
Windows and balcony doors	.	.	.	.	.	Specified conventionally
Entry doors and doorways (apart)	.	.	.	.	.	Specified conventionally
Garret floors	.	.	.	.	.	Specified conventionally
Floors over crawlways or over unheated underground floors	.	.	.	.	.	Specified conventionally

Figure 10 provides assisting meanings in the form of the building's total thermal transfer rate, calculated in line with the technique outlined in Section 2.

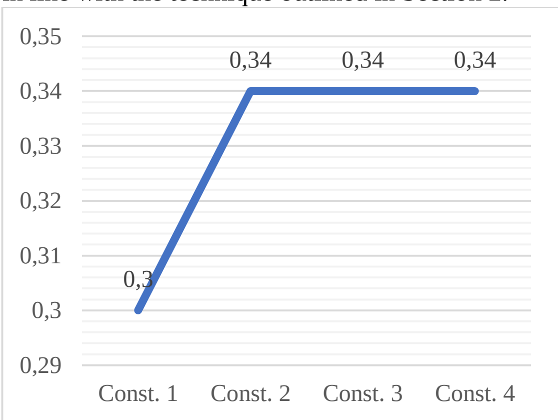


Figure 10: Meanings of the building's total thermal transfer rate.

Table 8 provides the results of the analysis of specific performance of the building, calculated in line with the calculation technique outlined in Section 2.

Table 8: Specific performance of the building.

Exponent	Standard Meaning of the Exponent	Calculated Specified Meaning of the Exponent (Str. 1)	Calculated Specified Meaning of the Exponent (Str. 2)	Calculated Specified Meaning of the Exponent (Str. 3)	Calculated Specified Meaning of the Exponent (Str. 4)	Notice
Specific heat-protective performance of the building, k_{total}, W/(m^3·°C)	.	.	.	.		Specified in line with Section 2.3
Specific ventilating performance of the building $k_{vent.}$, W/(m^3·°C)						Specified conventionally
Specific performance of domestic heat liberations of the building, $k_{domestic}$, W/(m^3·°C)						Specified conventionally
Specific performance of heat inputs to the building from solar irradiation, $k_{irrad.}$, W/(m^3·°C)						Specified conventionally

Table 9 provides the needed accepted coefficients to define the aggregate power effectiveness exponents and power loads of the building.

Table 9: Meanings of coefficients to define the aggregate power effectiveness exponents and power loads of the building.

Exponent	Standard Meaning of the Exponent
Heating automatic control effectiveness factor, ζ	.
Factor reflecting the decrease in heat consumption in residential buildings equipped with door-to-door heat measurement, ξ	.
Factor reflecting the decrease in the application of heat inputs when they exceed heat losses, v	.
Factor reflecting the assisting heat losses from the heating service, β_h	.

Figure 11 provides the results of calculating the aggregate power effectiveness exponent of the building in the form of the specific heat power consumption for heating and ventilating during the heating period for various outer wall shells.

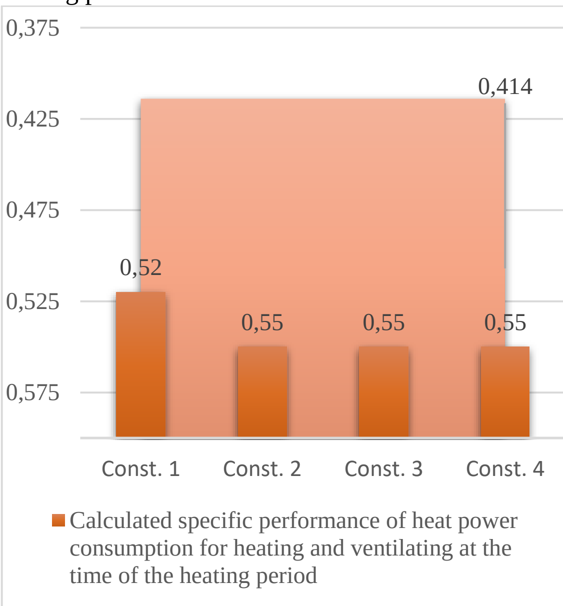


Figure 11: Meanings of the aggregate exponents of the building's power effectiveness.

Figure 12 provides the results of calculating power loads in the form of specific heat power consumption and total heat power consumption for heating and ventilating at the time of the heating period, as well as the building's total heat losses at the time of the heating period, categorized by forms of outer shells.

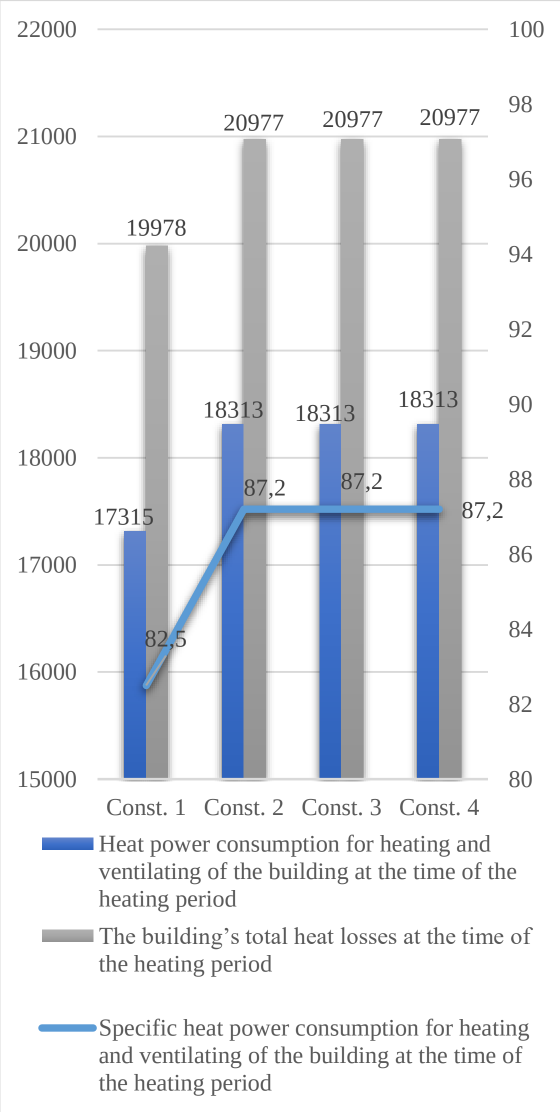


Figure 12: Meanings of the building's power loads.

The analysis identified that the efficiency of the offered new design was also confirmed by the results of the building's heat-protective study, where the specific performance exponents and power loads of the building demonstrated up to 5% higher efficiency compared to other studied designs.

4 CONCLUSIONS

The study on the modernization of buildings using innovative wall structures compared to traditional forms identified that the use of innovative power-effective blocks in outer wall shells can lead to significant heat power savings. The analysis in ANSYS of the resistance to heat transfer of wall structures, taking into account the use of innovative blocks compared to existing ones, showed that the offered design using the Porotherm 38 conventional brick is 1.28 times more effective in terms of resistance to heat transfer compared to traditional facade structures. Analogous results substantiating the effectiveness of the offered new design utilizing the Porotherm 38 conventional brick were obtained in the study of the building's heat shield. The assisting meanings, specific performance, aggregated power effectiveness exponents, and power loads of the building demonstrated a medium increase in efficiency of 5% compared to other studied designs. The aggregate study outlined in this work demonstrated that the modernization of outer shells utilizing innovative blocks significantly improves the thermotechnical performance of buildings. It was also established that the use of power-effective innovative blocks can significantly enhance the building's total power effectiveness class.

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