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Performance Analysis of Green Building with Natural Stone Coating Wall in the Black Sea Region

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Abstract: This study presents an integrated numerical and multi-criteria decision-making framework to evaluate and optimize building envelope designs for energy efficiency under the climatic conditions of the Black Sea Region, Turkey. A total of 108 alternative wall configurations were systematically generated by combining three wall types, five natural stone claddings, and two insulation materials. High-resolution thermal simulations were conducted using ANSYS to assess temperature distribution and heat transfer behavior across the building envelope under fixed indoor thermal comfort conditions. The simulation results were first evaluated from an energy-performance perspective, revealing that wall systems incorporating aerated concrete, EPS insulation, and Niğde marble cladding, particularly in sandwich configurations, exhibited the most favorable thermal behavior, while configurations using Giresun granite showed the poorest energy performance due to higher thermal conductivity. To complement the energy-focused analysis, an analytic hierarchy approach (AHP) was applied as a multi-criteria material selection tool, integrating mechanical and durability-related properties with thermal conductivity. Under this broader evaluation framework, Giresun granite was ranked as the optimal material owing to its superior mechanical performance, despite its unfavorable thermal behavior. The results demonstrate that material optimality in building envelope design is inherently context-dependent. While Niğde marble is preferable for energy-efficient envelope applications, Giresun granite becomes dominant when mechanical durability and long-term performance are prioritized. The combined use of ANSYS simulations and AHP provides a robust, transparent, and adaptable decision-support methodology for context-specific building envelope design.

Keywords: natural wall cladding stone, energy-efficient building, ANSYS analysis, analytic hierarchy approach

1. Introduction

The building envelope is described as "the climate moderator also provides the first line of defense against the impact of the external climate on the indoor environment" [1]. The roof's slope, the materials of the walls, the size of the windows and doors, and the characteristics of the building materials that control the temperature of the space are all components of the structure [2]. The outside walls make up the majority of the building envelope and serve as the primary barriers that shield the interior of the structure from the elements [3]. As a result, the shapes and materials of building envelopes provide each building a significant visual identity while organizing the interaction between the internal and external surroundings [4]. Apart from transparent glass windows and apertures, the majority of heat loss in buildings is caused by walls and ceilings with inadequate thermal insulation. If other building components are not adequately insulated, more heat leaks occur, leading to thermal bridges [5]. The appropriately constructed components of the cladding structure allow for control of the external environment's thermal impact on the interior of the building. Many design considerations influence the quantity of heat exposure [6]. The material and consistency of the wall, the temperature differential between the two sides of the wall, and the wall thermal conductivity measure (k) all have an impact on heat input by conduction [7]. Thermal conductivity is measured by the impact of temperature over a specific period of time. Depending on the material's characteristics and density, the index k may change [8]. The heat transfer coefficient (U-value) can therefore be calculated using these values. The ability of the building material to withstand high temperatures is one of its properties [9]. The fundamental thermal conductivity of a compound structure is its U-value. The more isolated the structural element is, the lower the U-value [10]. For these reasons, components that affect thermal characteristics and alter in response to different kinds of impacts without altering their own chemical properties are referred to as thermophysical components [11, 12].

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For a variety of reasons, including their natural beauty and thermal efficiency, natural stones are among the purest materials that may be used in building construction. Over millions of years, pressure and the presence of appropriate binders combined to form the diverse mineral combinations that make up natural stones. There are currently between 4500 and 5000 different types of natural stone accessible in the world. Natural stones have been utilized for thousands of years, as seen by Egyptian, Ancient Greek, and Roman construction [13]. These societies were all aware of the many benefits this natural substance provided. Fortunately, we may considerably benefit from the knowledge ancient and traditional builders have earned over the previous millennium and earlier in building with natural stones in today's world, where regulations are imposed for sustainable design, development, and construction processes [14]. In terms of extraction, energy consumption, processing, recyclability, waste output, and combustibility, they have several benefits, especially for green buildings. The best method for methodically producing sustainable architecture is certified green buildings. They are also regarded as the cornerstone of sustainable development because of their duty to balance the long-term effects on the environment, society, and economy. This article attempts to review the energy performance of different natural stone uses for green buildings in energy and environmental design [15].

As mentioned above, natural stones are one of the most popular and oldest materials utilized in exterior walls due to their durability and abundance. Nevertheless, there are numerous instances of stone facades that do not satisfy exterior wall performance standards, even though stone is an incredibly durable material. Naturally, the process of developing the building envelope in the most energy-efficient way, which includes the construction and service life phases throughout the early design process, determines a stone wall's performance. Important prerequisites for the anticipated performance of stone walls include the selection of the proper stone type as an exterior wall element, taking into consideration the climate of the area where it will be applied, that is, the specification and correct detailing of components during the design phase, its installation with skilled workmanship during the construction phase, and the use of proper maintenance techniques throughout its service life [16–18]. A high-quality exterior wall cladding material may function poorly if the standards of each step are not met. Natural stone is prone to bending, cracking, falling, and separating. Therefore, a structure with poor performance integrity could result from improperly prepared and constructed construction features. The performance of natural stone as an exterior wall building and cladding material has significantly improved in recent years [19].

An eco-friendly and sustainable building material is natural stone. The environmental impact of its extraction is negligible. Furthermore, natural stone does not require replacement as frequently as other materials because it can endure for hundreds of years with the right upkeep. At the conclusion of its life cycle, natural stone can be recycled and used again. For thousands of years, it has also been a lovely and adaptable material used in building and interior design. It is a classic and sophisticated material that can give any house a hint of refinement and grandeur. When utilized as a building material or as wall cladding on a building's exterior walls, these stones can help keep a house cool in the summer and warm in the winter. Both energy use and electricity costs may be decreased as a result [20].

Granite, marble, slate, sandstone, and quartzite are the most prevalent natural stones. Each piece of natural stone has a distinct texture and pattern, which is one of its distinctive characteristics. Because stones can have a variety of hues and textures due to their natural formation, they are nearly always an esthetically pleasing option [21].

This article examines the natural stones' technical features when utilized as cladding materials on the building's external shell from an architectural perspective, aiming to bring the building closer to optimal energy efficiency and, by selecting the right stone for the application, to design that is more climate-responsive, natural, and sustainable, as well as to green building requirements [22].

Prior to the development of computer-aided building energy simulation, engineers and architects frequently used complex formula-based solution techniques to go beyond conventional design concepts and mostly relied on manual calculations utilizing pre-selected design circumstances. It would be absurd to expect energy-efficient designs to be tested for large or complex structures without using computer-aided, detailed building simulation systems. Architects and engineers may now evaluate new designs before moving forward with construction and installation, thanks to building simulation software that runs on personal PCs [18]. Professionals can also extend design principles to include new advancements and technologies by using parametric analysis. This enables them to make recommendations for greater energy savings. There are many numerical programs for analyzing combinations of different structural materials in the construction industry. Some of the package programs used for this purpose are ANSYS, ABAQUS, LUSAS, DIANA, etc., which are based on the finite element methodology. In this study, the ANSYS analysis was utilized to determine the temperature distribution in the wall.

Through the ANSYS software package, numerous engineering tasks are available on the main screen via the Workbench platform. ANSYS Workbench serves as a guiding framework for numerous physical analyses. It enables the management of advanced parameters. Therefore, it can be efficiently utilized in product development depending on the software. Analyses of engineering problems in different disciplines can be managed centrally with the help of ANSYS Workbench [23]. Qu and his coworkers created a numerical model of a 2-story concrete masonry building under the influence of cyclic lateral loading (semi-static) on walls in orthogonal directions. To test the accuracy of the model created to represent the structure, they compared the results obtained from experimental analysis for 10 different walls. The models were evaluated separately for each wall and tested against the numerical results of the building to investigate its ductility under eccentric loading [24]. Using less energy to accomplish the same work or achieve the same outcome is known as energy efficiency. It is an approach that aims to use less energy by heating, cooling, and operating electronic devices in energy-efficient buildings and homes using low energy and by adapting energy produced by energy-efficient production facilities and/or renewable energy sources to buildings. One of the simplest and most economical ways to fight climate change, lower consumer energy bills, and boost company competitiveness is through energy efficiency. In order to achieve net-zero carbon dioxide emissions through decarbonization, energy efficiency is also essential. Energy efficiency can help the environment, society, and health in addition to saving money and improving the flexibility and dependability of the electrical system [25–27].

In buildings, energy savings can be achieved by creating energy-efficient and weather-appropriate improvements like adding exterior wall cladding materials or insulation to the building envelope, using lighting that consumes less energy, or installing a heat pump. Because conventional power plants use fossil fuels that release greenhouse gases and contribute to air pollution, reducing energy usage is essential in the fight against climate change. Additionally, households and structures that use less energy are better prepared to switch to renewable energy, which emits very little or no negative emissions. Enhancements in energy efficiency reduce stress and congestion on the electrical grid by decreasing the amount of electricity on the grid at any given time, known as load. Less load can prevent power outages. Human health is directly impacted by cleaner air, water, and soil, all of which can be achieved by reducing the usage of fossil fuels. Recent global studies have increasingly focused on the development of high-performance, demand-responsive, and energy-efficient commercial and residential buildings, emphasizing the role of building envelope design and material selection in supporting the transition from a decarbonized energy sector by 2035 to a fully decarbonized energy system by 2050 [28–32]. It is important to raise the energy performance of facilities and buildings in countries. This is because approximately two-thirds of carbon dioxide emissions are greenhouse gases emitted from buildings [33, 34].

In this study, based on the climatic conditions affecting the Black Sea region, a building exterior wall was designed with three diverse wall kinds (sandwich internally and externally insulated), three diverse building materials (concrete block, brick, and aerated concrete), five different natural stone wall cladding materials (Niğde marble, Çamardı marble, Kayseri travertine, Konya andesite, and Giresun granite), and two different insulation materials (rock wool and EPS) to create 108 alternative scenarios. Accordingly, this study is structured around two complementary but distinct objectives. The primary objective is to optimize the energy performance of building envelope systems under the climatic conditions of the Black Sea region through ANSYS-based thermal simulations, focusing on temperature distribution and heat transfer behavior. The secondary objective is to demonstrate the applicability of the analytic hierarchy approach (AHP) as a decision-support tool for the selection of natural stone cladding materials by jointly considering thermal, mechanical, and durability-related criteria. These two objectives address different decision contexts and are intentionally evaluated separately.

2. Designing the Building Wall

Turkey's heating degree-days map is shown in Figure 1 [23]. The building envelope was planned using three different building materials (concrete block, brick, and aerated concrete) and two diverse insulation materials (EPS and rock wool) for each wall structure designed as a sandwich, externally and internally insulated. In this way, [3 wall structures × 2 insulation materials × 3 building materials] 18 different scenarios were designed. All scenarios were modeled again with and without five different natural stones (Niğde marble, Çamardı marble, Kayseri travertine, Konya andesite, and Giresun granite) used as wall cladding materials. A total of 108 [18 scenarios × (5 natural stones + 1 without natural stones)] different scenarios were obtained. Subsequently, all scenarios were analyzed and evaluated individually using the ANSYS software package in terms of temperature distributions. All alternative scenarios were analyzed for indoor comfort conditions in conjunction with the climatic conditions in the Black Sea region.

Figure 2 presents the wall models analyzed for sandwich, internally insulated, and externally insulated wall structures without the natural stone's use as a wall cladding material, and for the same wall types, the wall cladding materials utilized in the building envelope's outermost layer, including locally sourced wall stones (Niğde marble, Çamardı marble, Kayseri travertine, Konya andesite, and Giresun granite), are added as wall cladding materials for the same wall types.

The thermal performance of the building envelope configurations was evaluated using the ANSYS Workbench finite element platform. The analyses were conducted under steady-state thermal conditions, which are suitable for comparative assessment of wall systems under fixed climatic and indoor comfort scenarios. The objective was not to predict transient hourly energy consumption but to compare relative heat transfer behavior among alternative envelope configurations under identical conditions.

Indoor boundary conditions were defined by a constant indoor air temperature of 20 °C, representing standard thermal comfort conditions for residential buildings. Outdoor temperature was selected based on the climatic characteristics of the Black Sea region, located in Turkey's second climate zone, and was applied uniformly to all simulation scenarios to ensure direct comparability.

Convective heat transfer coefficients were defined as constant surface film coefficients on both interior and exterior wall surfaces, consistent with commonly adopted values in building envelope thermal analyses. Radiative heat transfer and moisture transport effects were not explicitly modeled, as the primary objective was to evaluate conductive heat transfer and temperature distribution across multilayer wall assemblies. All 108 wall

Figure 1
The Turkey heating degree-days map

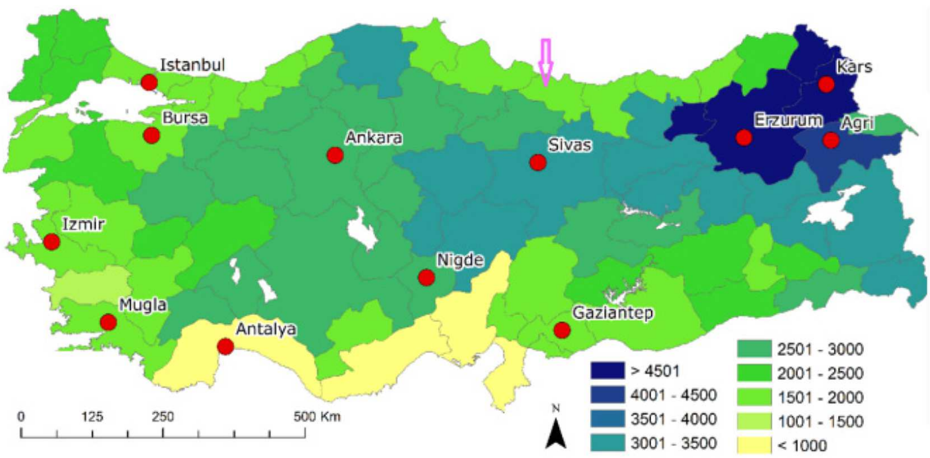
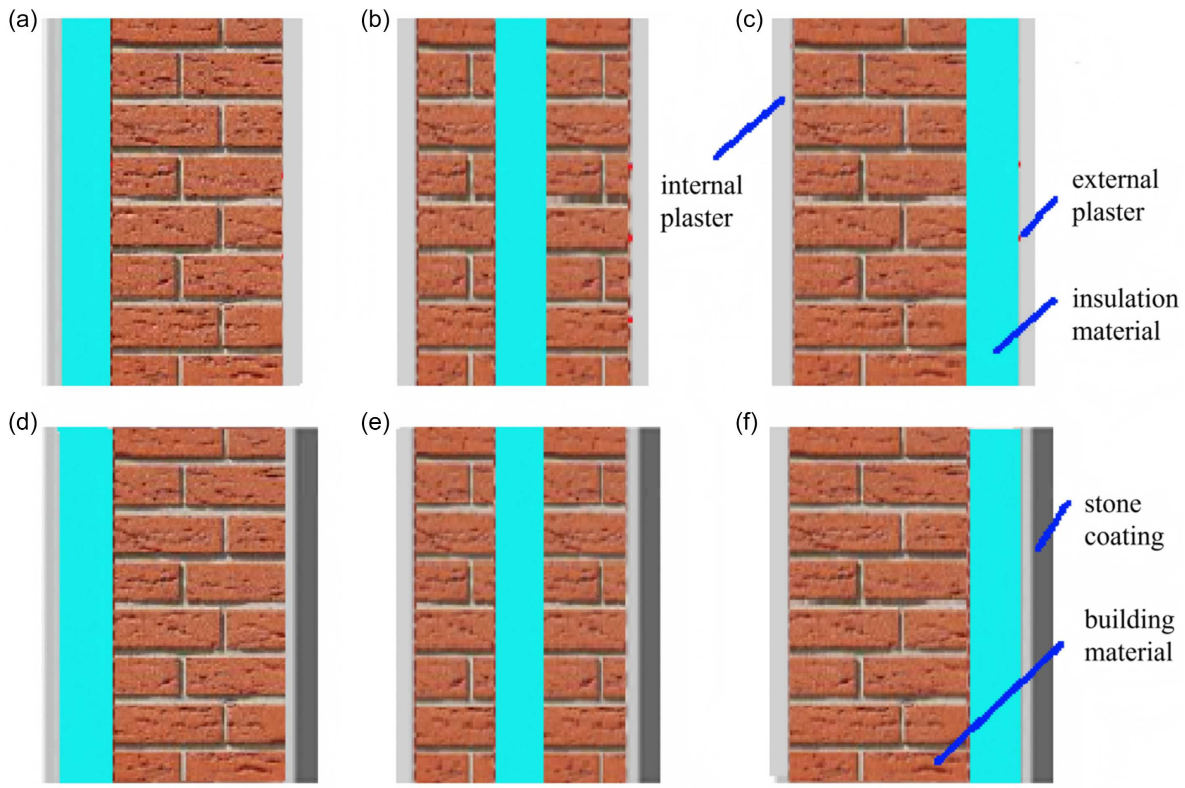


Figure 2
Models containing the components of wall structures from the inside out: (a) internally insulated, (b) sandwich wall, (c) externally insulated, (d) internally insulated wall with natural stone cladding material used on the building envelope's outermost layer, (e) sandwich wall with natural stone cladding material used on the building envelope's outermost layer, (f) externally insulated wall with natural stone cladding material used on the building envelope's outermost layer



configurations were analyzed deterministically under identical boundary conditions. No stochastic variation or repeated simulations were performed, as the study aims to establish a relative ranking of envelope alternatives rather than probabilistic performance estimates. Table 1 presents the definition of wall configurations and material combinations analyzed in ANSYS simulations. The materials' technical specifications of the building envelope are shown in Table 2 [12, 35, 36].

3. Numerical Modeling and ANSYS Thermal Simulation

Although building energy simulation tools such as EnergyPlus, DesignBuilder, and TRNSYS are widely used for whole-building energy-performance assessment, the primary objective of this study is to perform a detailed comparative analysis of heat transfer behavior across multilayer wall assemblies with different natural stone claddings. ANSYS was therefore selected due to its advanced finite element–based heat transfer capabilities, precise implementation of boundary conditions, and high spatial resolution in temperature distribution analysis. These features allow for controlled, scenario-based comparison of envelope alternatives under identical thermal loading conditions, which would be less straightforward to isolate using whole-building simulation platforms.

The thermal behavior of the wall assemblies was evaluated using a steady-state heat transfer model implemented in ANSYS. The analysis assumes one-dimensional heat conduction through multilayer wall sections under constant boundary conditions. Indoor air temperature was fixed at 22 °C in accordance with commonly accepted thermal comfort criteria for residential buildings, while outdoor design temperature values were defined based on Black Sea region climatic data.

Convective heat transfer was modeled using surface convection boundary conditions applied to the interior and exterior wall surfaces. Standard convection heat transfer coefficients were adopted, with an interior coefficient of 8.7 W/m²K and an exterior coefficient of 23 W/m²K, consistent with values commonly reported in building thermal analysis literature. Radiative heat transfer and moisture transport effects were not explicitly considered, allowing the analysis to focus on comparative thermal performance among wall configurations.

The steady-state assumption enables direct comparison of temperature distributions and heat transfer behavior across different wall and cladding alternatives under identical thermal loading conditions.

The graphical representation of the most efficient, second-best, and least efficient alternative types in terms of temperature distribution within the building envelope under regional climate conditions in the Black Sea Region, when natural stone is used and when it is not used, is presented in Figure 3. When all wall structures were evaluated, the best alternative building material was found to be aerated concrete, the best insulation material was EPS, and the best natural stone wall cladding was Niğde marble. Among the alternatives, the building material with the worst performance was concrete block, the insulation material

Table 1
Definition of wall configurations and material combinations analyzed in ANSYS simulations

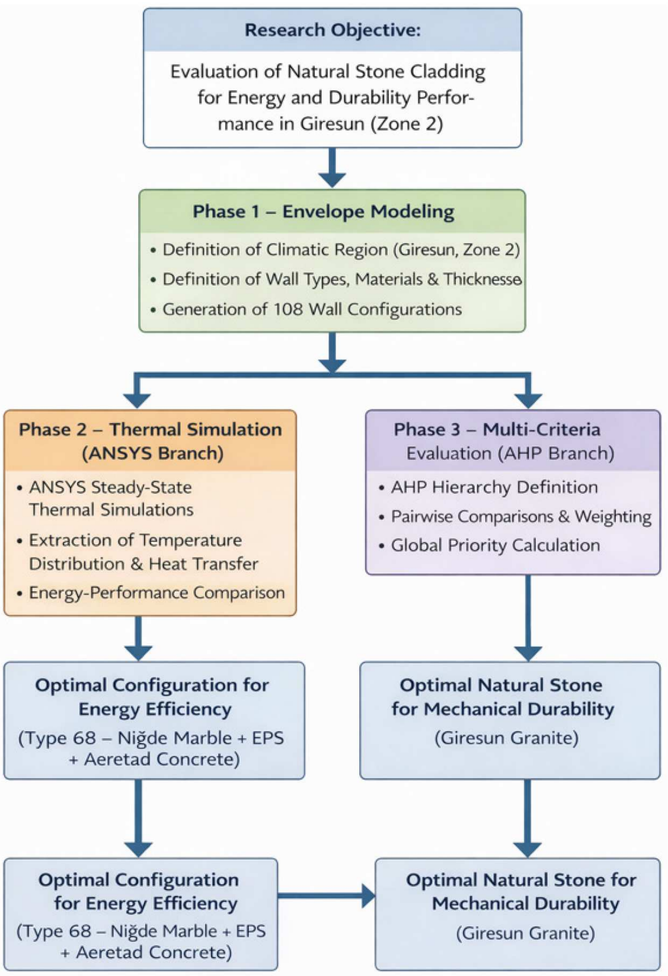
Type	Wall structure	Wall layers (from outside to inside)					
		Exterior cladding	Exterior plaster	Building material	Insulation material	Building material	Interior plaster
1–6		BM1–BM6	Available	Concrete block	Rockwool	Concrete block	Available
7–12	Sandwich	BM1–BM6		Brick		Brick	
13–18		BM1–BM6		Gas concrete		Gas concrete	
19–24		BM1–BM6		Not available		Concrete block	
25–30	External insulated	BM1–BM6				Brick	
31–36		BM1–BM6				Gas concrete	
37–42		BM1–BM6		Concrete block		Not available	
43–48	Internal insulated	BM1–BM6		Brick			
49–54		BM1–BM6		Gas concrete			
55–60		BM1–BM6		Concrete block	EPS	Concrete block	
61–66	Sandwich	BM1–BM6		Brick		Brick	
67–71		BM1–BM6		Gas concrete		Gas concrete	
73–78		BM1–BM6		Not available		Concrete block	
79–84	External insulated	BM1–BM6				Brick	
85–90		BM1–BM6				Gas concrete	
91–96		BM1–BM6		Concrete block		Not available	
97–102	Internal insulated	BM1–BM6		Brick			
103–108		BM1–BM6		Gas concrete			

Note: BM1: not available, BM2: Niğde marble, BM3: Çamardı marble, BM4: Kayseri travertine stone, BM5: Konya andesite stone, BM6: Giresun granite stone.
Note: All wall configurations consist of interior plaster, structural layer(s), insulation layer, exterior plaster, and optional natural stone cladding applied to the outermost surface. Each configuration was analyzed under identical boundary conditions to allow direct comparison of thermal performance.

Table 2
Technical specifications of materials in the building envelope

	Material	Thickness (m)	Density (g/cm³)	Thermal conductivity (W/mK)
wall covering materials	Niğde marble	0.03	2.41	0.55
	Çamardı marble	0.03	2.82	2.41
	Kayseri travertine stone	0.03	2.51	1.6
	Konya andesite stone	0.03	2.84	0.64
	Giresun granite stone	0.03	2.91	2.53
Insulation materials	Rockwool	0.05	0.200	0.040
	EPS	0.05	0.035	0.035
Building materials	Concrete block	0.2	2.3	1.63
	Brick	0.2	1.7	0.73
	Gas concrete	0.2	0.6	0.15
Exterior plaster	–	0.02	1.4	0.87
Interiror plaster	–	0.03	2.0	1.4

Figure 3
Flowchart illustrating the research methodology, including wall configuration generation, ANSYS-based thermal simulations, extraction of energy-performance indicators, AHP-based multi-criteria evaluation, and final comparison of results



with the worst performance was rock wool, and the natural stone wall cladding with the worst performance was Giresun granite. The worst energy performance was obtained with internal insulation, while the best energy performance was mostly obtained with sandwich walls, followed by externally insulated walls. The classification of alternatives as "best" and "worst" is based on the comparative evaluation of temperature distribution and heat transfer behavior across the wall section under identical boundary conditions. Type numbers correspond to the wall configurations defined in Table 1 and summarized for key cases in Table 3.

When aerated concrete was used as the building material, EPS as the isolation material, and Niğde marble as the natural stone for the building envelope's design in the Black Sea Region, the grid views according to the wall structures are given in Figure 4. When concrete blocks were used as the building material, rock wool as the isolation material, and Giresun granite as the natural stone for the building envelope design in the Black Sea Region, the mesh views according to the wall structures are given in Figure 5.

It should be emphasized that the ANSYS-based results presented in this section evaluate the wall alternatives solely from an energy-performance perspective. Therefore, the identification of Niğde marble as the most favorable natural stone cladding is directly linked to its thermal behavior and its contribution to reducing heat transfer through the building envelope, independent of mechanical or durability considerations.

All temperature distributions are obtained under identical boundary conditions. The classification of alternatives reflects relative energy performance based solely on heat transfer behavior. These analyses determined that the energy performance could vary depending on the use of five different natural stones as wall cladding materials in the outer layer of buildings planned for construction in the Black Sea Region. Based on the temperature distributions in 108 alternative scenarios designed using the ANSYS software package, the "Type 68" alternative scenario was determined to be the most energy-efficient wall type. In this alternative, the design was implemented utilizing aerated concrete as the building material, EPS as the isolation material, Niğde marble as the natural stone for wall cladding, and sandwich walls as the

Table 3
Definition of best- and worst-performing wall configurations discussed in the ANSYS software

Type	Wall structure	Structural material	Insulation type	Natural stone cladding	Performance note
68	Sandwich	Aerated concrete	EPS	Niğde marble	Best energy performance
86	Externally insulated	Aerated concrete	EPS	Niğde marble	High energy performance
42	Internally insulated	Concrete block	Rock wool	Giresun granite	Worst energy performance

Figure 4
Graphical representation of temperature distributions showing the least and most efficient wall alternatives: (a) the option with the best performance (Type 68), (b) the option with the second-best performance (Type 86), (c) the option with the worst performance when natural stone cladding material is used (Type 42), (d) the option with the worst performance when natural stone cladding material is not used (Type 37)

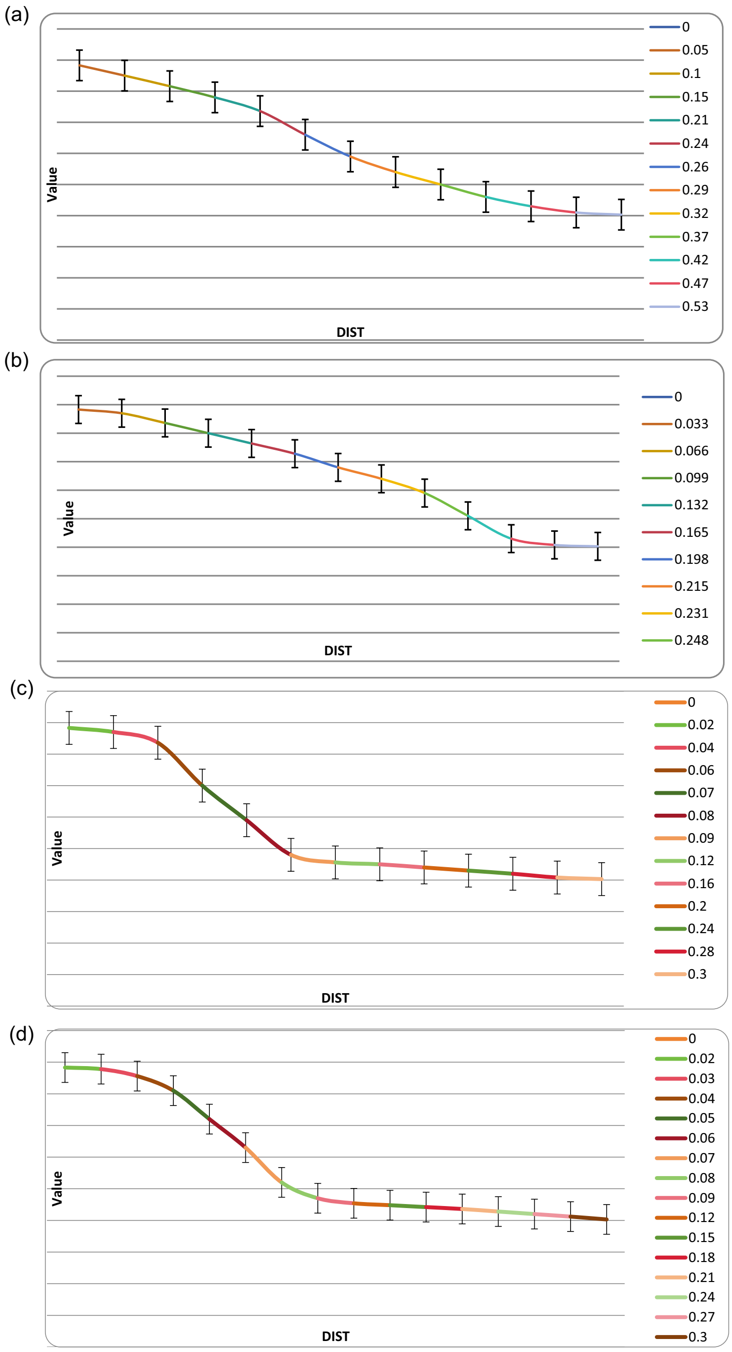
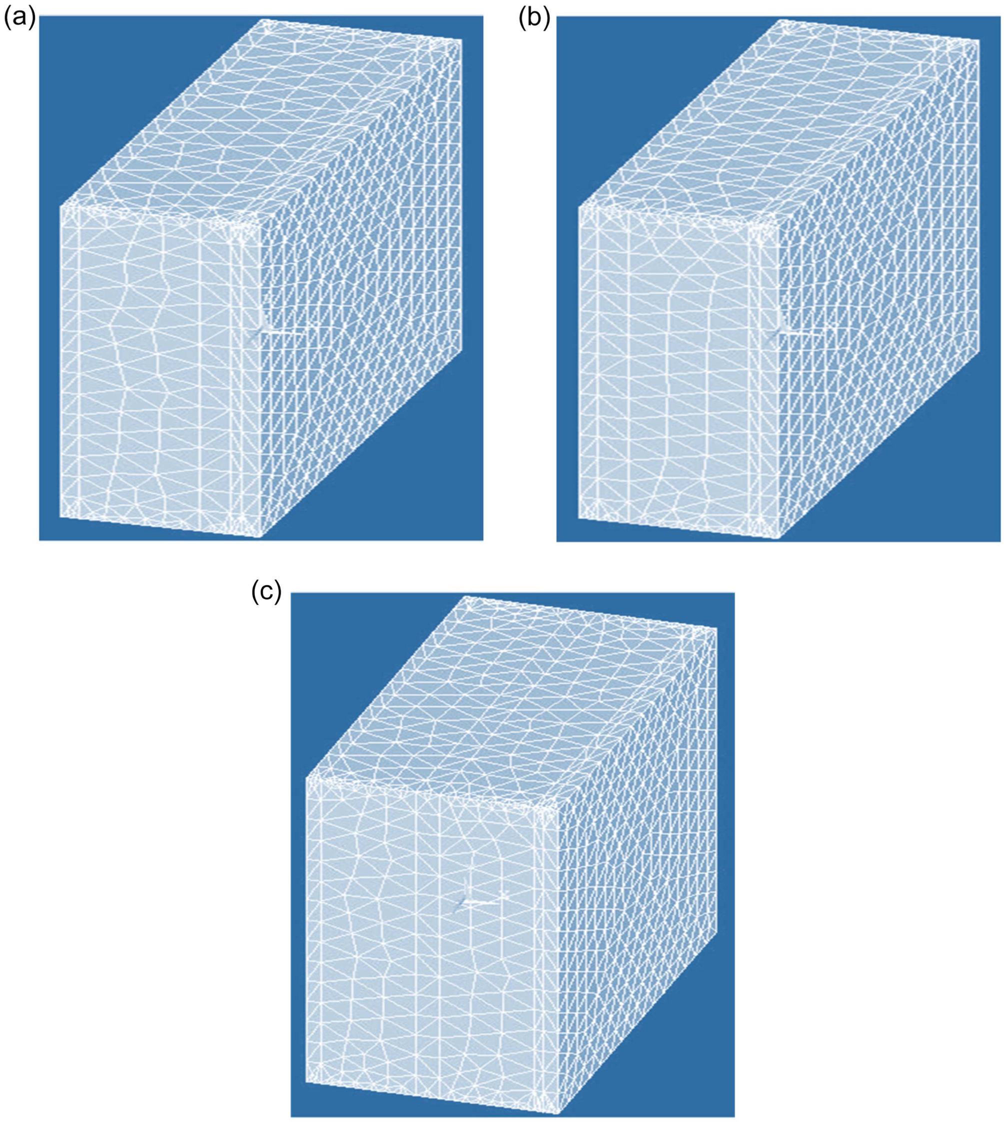


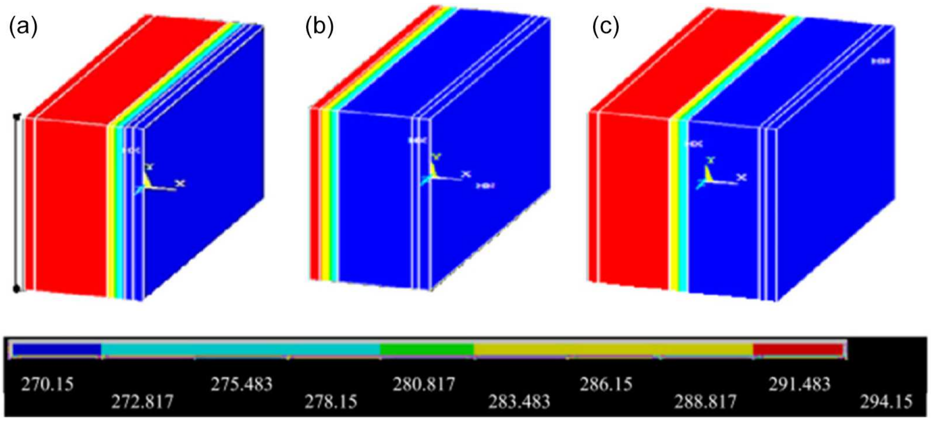
Figure 5
Mesh views of the best-performing materials in building envelope design according to wall structures: (a) best alternative for externally insulated wall type (Type 86), (b) best alternative for internally insulated wall type (Type 104), (c) best alternative for sandwich insulated wall type (Type 68)



wall structure. In terms of energy performance, the worst alternative when using wall stone was determined to be "Type 42." In this alternative, the design was implemented using concrete blocks as the building material, rock wool as the insulation material, Giresun granite as the natural stone wall cladding, and an internally insulated wall structure. When all alternatives were evaluated, aerated concrete was determined to be the most efficient building material, EPS was determined to be the most efficient insulation material, Niğde marble was determined to be the most efficient natural stone wall cladding, and externally insulated walls were determined to be the most efficient wall structure, followed by sandwich walls. It was determined that sandwich walls contribute more positively to energy efficiency compared to internally insulated walls. Giresun granite stone was observed to be the wall cladding material with the worst performance.

Vector views of the worst-performing materials in building envelope design according to wall structures are given in Figure 6. The results obtained from the ANSYS simulations and the AHP represent two distinct yet complementary evaluation perspectives. The ANSYS-based analysis focuses exclusively on the thermal behavior of the building envelope, where lower thermal conductivity directly contributes to reduced heat transfer. Within this framework, Niğde marble emerges as the most energy-efficient natural stone cladding, while Giresun granite exhibits the poorest energy performance due to its high thermal conductivity. Conversely, the AHP analysis addresses a broader material selection problem in which mechanical strength and durability-related criteria are intentionally prioritized over thermal performance. As a result, Giresun granite is ranked as the optimal material due to its superior compressive strength, flexural strength, and abrasion resistance, despite its unfavorable thermal behavior. This divergence highlights that material optimality is inherently context-dependent. A material identified as optimal for energy-efficient envelope design may differ from the material preferred for structural durability and long-term performance. Therefore, the AHP results do not contradict the ANSYS findings but rather

Figure 6
Vector views of the worst-performing materials in building envelope design according to wall structures: (a) worst alternative for externally insulated wall type (Type 24), (b) worst alternative for internally insulated wall type (Type 42), (c) worst alternative for sandwich insulated wall type (Type 6)



complement them by illustrating how decision outcomes change when evaluation priorities are modified.

4. The Analytic Hierarchy Approach

While the thermal simulations provide insight into energy-efficient envelope configurations, material selection in real-world applications often requires the simultaneous consideration of multiple performance criteria. For this reason, the AHP is employed in this study as a complementary analysis to evaluate natural stone alternatives from a multi-criteria decision-making perspective, where mechanical strength and durability characteristics are intentionally prioritized alongside thermal properties.

The pairwise comparison judgments used in the AHP analysis were derived from expert consensus among researchers with academic and professional expertise in building materials, structural engineering, and energy-efficient building design.

The analytical hierarchy approach is a structured and robust technique within the broader field of multi-attribute decision-making [37]. Thomas Saaty created it in the 1970s; its capacity to break down a complicated choice problem into a hierarchical framework is its fundamental strength, moving from the overall goal at the top to attributes, sub-attributes, and alternatives in subsequent levels [38–40]. This methodology is particularly powerful because it incorporates both quantitative and qualitative data, and most importantly, it systematically captures subjective expert judgments through a series of pairwise comparisons [41]. These comparisons, made using a fundamental scale of absolute numbers, allow decision-makers to articulate the relative significance of criteria and the efficiency of alternatives in a consistent manner [42]. A key feature of the analytical hierarchy approach is its built-in mechanism to check for consistency in judgments, ensuring that the derived priorities are logically sound [43]. By synthesizing the results, the analytical hierarchy approach generates a clear priority ranking of the available alternatives, providing a mathematically grounded and transparent rationale for the final decision [44]. This makes it an important tool in fields such as resource management, business strategy, and, as demonstrated in this study, engineering material selection, where multiple conflicting criteria must be balanced objectively [45, 46].

The ranking reflects a multi-criteria evaluation prioritizing mechanical strength and durability over thermal performance. For these reasons, this approach can provide a structured, quantitative method to resolve the trade-offs between the conflicting criteria [compressive strength, density, thermal conductivity, water absorption, abrasion loss, and flexural strength], identifying the most balanced material for general applications.

Comparative technical characterization of selected natural stones for construction applications used in this research is given in Figure 7.

The analytical hierarchy approach was implemented in the following stages:

Stage 1. Hierarchy structuring

A 3-step decision hierarchy was defined:

Goal (step 1)—Select the optimal natural stone.

Criteria (step 2)—Thermal conductivity (k), density (ρ), compressive strength, abrasion loss, water absorption, and flexural strength.

Options (step 3)—Niğde marble, Çamardı marble, Kayseri travertine, Konya andesite, and Giresun granite.

Stage 2. Pairwise comparison of criteria and weight calculation

In Table 4, a pairwise comparison matrix was constructed depending on Saaty's 1–9 scale, reflecting the relative significance of each criterion for a general-purpose construction material where mechanical durability is prioritized, followed by thermal and density properties.

Mechanical strength (compressive, flexural) and durability (abrasion loss) were considered the most critical for structural integrity and long-term performance. Hence, they were given equal and high importance (values of 5 and 7) over other criteria.

Thermal conductivity was considered moderately more important than density but less important than mechanical criteria.

Water absorption was considered the least critical among the set, as it primarily affects long-term weathering and freeze-thaw durability, which can be mitigated in many applications.

The normalized matrix and the resulting priority vector (weights) were calculated. The ratio of consistency (CR) was found to be 0.028, which is well below the 0.10 threshold, indicating a highly consistent judgment matrix. Normalized matrix and criteria weights are presented in Table 5.

Stage 3. Evaluating alternatives against each criterion

In Table 6, the five stones were compared in a pairwise manner. The resulting local priority vectors are shown for each criterion. For beneficial criteria (thermal conductivity, compressive

Figure 7
Comparative technical characterization of selected natural stones for construction applications used in this research

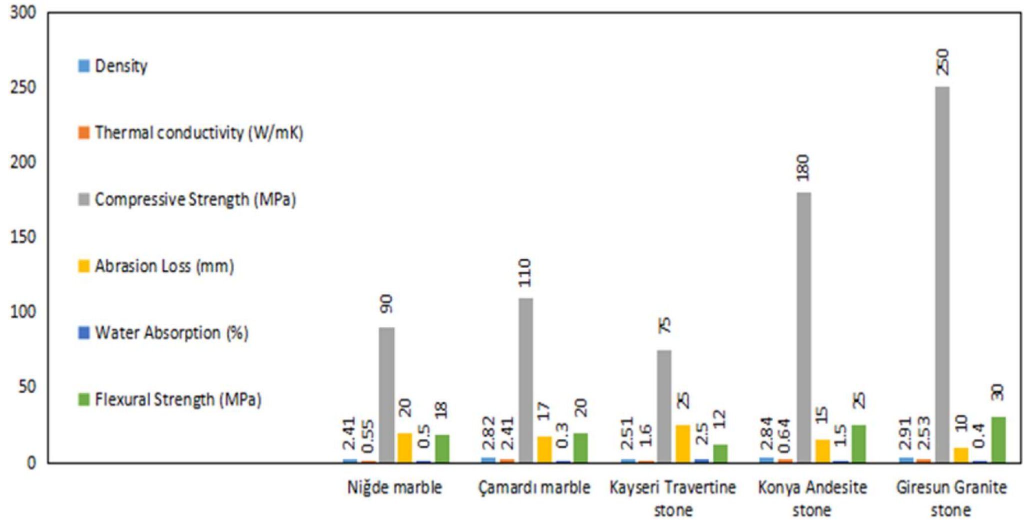


Table 4
Pairwise comparison matrix for criteria

Criteria	Thermal conductivity	Density	Compressive strength	Abrasion loss	Water absorption	Flexural strength
Thermal conductivity	1	3	1/3	1/3	3	1/3
Density	1/3	1	1/5	1/5	3	1/5
Compressive strength	3	5	1	1	7	1
Abrasion loss	3	5	1	1	7	1
Water absorption	1/3	1/3	1/7	1/7	1	1/7
Flexural strength	3	5	1	1	7	1

Table 5
Normalized matrix and criteria weights

Criteria	Normalized priorities	Priority vector (weight) (%)
Thermal conductivity	0.085	8.5
Density	0.050	5.0
Compressive strength	0.263	26.3
Abrasion loss	0.263	26.3
Water absorption	0.034	3.4
Flexural strength	0.305	30.5

Table 6
Local priorities of alternatives for each criterion

Alternative	k (8.5%)	ρ (5.0%)	Comp. str. (26.3%)	Abras. loss (26.3%)	Water abs. (3.4%)	Flex. str. (30.5%)
Niğde marble	0.055	0.288	0.104	0.088	0.224	0.097
Çamardı marble	0.263	0.104	0.127	0.106	0.373	0.108
Kayseri travertine	0.160	0.157	0.087	0.074	0.037	0.065
Konya andesite	0.160	0.096	0.208	0.123	0.075	0.135
Giresun granite	0.362	0.355	0.474	0.609	0.291	0.595

Table 7
Calculation of score

Niğde marble	$(0.055 \times 0.085) + (0.288 \times 0.050) + (0.104 \times 0.263) + (0.088 \times 0.263) + (0.224 \times 0.034) + (0.097 \times 0.305)$	0.104
Çamardı marble	$(0.263 \times 0.085) + (0.104 \times 0.050) + (0.127 \times 0.263) + (0.106 \times 0.263) + (0.373 \times 0.034) + (0.108 \times 0.305)$	0.132
Kayseri travertine	$(0.160 \times 0.085) + (0.157 \times 0.050) + (0.087 \times 0.263) + (0.074 \times 0.263) + (0.037 \times 0.034) + (0.065 \times 0.305)$	0.082
Konya andesite	$(0.160 \times 0.085) + (0.096 \times 0.050) + (0.208 \times 0.263) + (0.123 \times 0.263) + (0.075 \times 0.034) + (0.135 \times 0.305)$	0.162
Giresun granite	$(0.362 \times 0.085) + (0.355 \times 0.050) + (0.474 \times 0.263) + (0.609 \times 0.263) + (0.291 \times 0.034) + (0.595 \times 0.305)$	0.520

Table 8
Final ranking of natural stones

Rank	Alternative	Global priority (score)
1	Giresun granite	0.520
2	Konya andesite	0.162
3	Çamardı marble	0.132
4	Niğde marble	0.104
5	Kayseri travertine	0.082

strength, and flexural strength), higher values received higher priorities. For non-beneficial criteria (density, abrasion loss, and water absorption), lower values received higher priorities.

Stage 4. Synthesis for final ranking

The global priority for each alternative was calculated by summing the products of its local priority and the global weight of each criterion. Calculation of score and final ranking of natural stones are given in Tables 7 and 8, respectively.

Giresun granite's (1st) supremacy is driven by its top-tier performance in compressive strength (250 MPa), abrasion loss (10.0 mm), and flexural strength (30 MPa), which collectively make up more than 80% of the decision weight. Giresun granite's high thermal conductivity is an additional benefit. This makes Giresun granite an ideal all-rounder for structural applications, high-traffic flooring, and facades.

Konya andesite (2nd) presents a balanced profile with very high compressive strength (180 MPa) and good flexural strength (25 MPa). Konya andesite's lower rank compared to granite is due to Konya andesite's significantly higher abrasion loss (15.0 mm vs 10.0 mm), indicating lower wear resistance.

Çamardı marble (3rd) distinguishes itself with an excellent combination of high thermal conductivity (2.41 W/mK) and the lowest water absorption (0.30%), making Çamardı marble suitable for underfloor heating systems and humid environments. However, Çamardı marble's mechanical properties are not as strong as the top two ranked stones.

Niğde marble's (4th) low ranking is a consequence of Niğde marble's mediocre performance in the highly weighted mechanical criteria. While the Niğde marble has the lowest thermal conductivity, which could be beneficial for thermal inertia, this property was not weighted heavily enough in this specific decision context to offset its mechanical limitations.

Kayseri travertine (5th) is penalized by its high water absorption (2.50%) and the highest abrasion loss (25.0 mm), which are significant drawbacks for durability. Kayseri travertine's lower mechanical strengths further contribute to Kayseri travertine's last-place position.

It is crucial to note that this ranking is a function of the assigned criterion weights. A decision scenario prioritizing energy efficiency would involve significantly increasing the weight for thermal conductivity and density, potentially making Çamardı marble or Niğde marble more competitive. Similarly, for a purely decorative, nonstructural interior application, the weights for mechanical properties could be reduced, altering the ranking.

The implications of these multi-criteria rankings, together with the ANSYS-based energy-performance results, are discussed in the following section.

5. Discussion

The results of ANSYS simulations and AHP analysis clearly demonstrate separation energy-based and performance-based material selection results. The thermal analysis based on the ANSYS reveals that Nigde marble has high energy performance because of its lower thermal conductivity and its applicability for decreasing heat flow through the building. Conversely, the multi-attribute decision approach, based on the mechanical strength and durability-related features, ranks Giresun granite as the best option, owing to its excellent compressive strength and flexural strength, and the least wear among all the materials considered.

This explains the perfect energy efficiency suitability of Niğde marble and the superior mechanical durability of Giresun granite. Such a discrepancy does not mean that the two methods contradict each other; it rather shows that "optimal" material is dependent on the use scenario even in the building envelope design.

5.1. Implications for energy-efficient envelope design

The ANSYS-based thermal simulations clearly demonstrate that the energy performance of the building envelope is strongly influenced by the thermal conductivity of the exterior cladding material and its interaction with the wall structure and insulation system. Among the evaluated alternatives, wall configurations incorporating aerated concrete, EPS insulation, and Niğde marble cladding—particularly within sandwich wall systems—exhibited the most favorable temperature distributions and lowest heat transfer rates.

These results indicate that, when energy efficiency is the primary design objective, natural stones with relatively lower thermal conductivity, such as Niğde marble and, to a lesser extent, Çamardı marble, are more suitable as exterior cladding materials. In contrast, Giresun granite consistently exhibited the poorest thermal performance due to its high thermal conductivity, confirming that superior mechanical strength does not necessarily translate into improved envelope energy efficiency.

The findings align with previous studies emphasizing the dominant role of material thermal properties in envelope performance, while also highlighting that the contribution of natural stone cladding to energy efficiency is highly dependent on the overall wall assembly and insulation strategy.

5.2. Implications for multi-criteria natural stone selection

While energy performance is a critical consideration in building envelope design, material selection in practice often involves balancing multiple, sometimes conflicting, performance criteria. The AHP applied in this study demonstrates how material rankings shift when mechanical strength and durability-related properties are prioritized alongside thermal behavior.

Under this broader decision framework, Giresun granite emerged as the optimal material due to its superior compressive strength, flexural strength, and abrasion resistance, despite its unfavorable thermal performance. This result underscores the inherent trade-off between thermal efficiency and structural durability in natural stone selection.

From a practical perspective, the results suggest that architects and engineers should adopt a context-dependent approach: marbles such as Niğde or Çamardı may be preferable for energy-efficient residential envelopes, whereas granite may be more appropriate for high-traffic façades, public buildings, or applications where long-term mechanical performance dominates design priorities.

Ultimately, the combined use of ANSYS simulations and AHP analysis provides a flexible decision-support framework, allowing practitioners to adjust material choices according to specific project objectives rather than relying on a single, universal definition of optimality.

Limitations of the Study

The findings of this study should be interpreted in light of several limitations. First, the numerical simulations were conducted for a single climatic region, and the relative performance of wall configurations and natural stone claddings may differ under heating-dominated or cooling-dominated climatic conditions. Second, the ANSYS-based analysis focused on heat transfer mechanisms and did not consider moisture transport, material aging, or degradation effects, which may influence long-term envelope performance. Third, the wall models were based on idealized one-dimensional and layered constructions, and realistic three-dimensional façade geometries, detailing effects, and construction imperfections were not explicitly modeled. Future studies may address these aspects through coupled heat–moisture simulations, multi-climate comparisons, and advanced three-dimensional façade modeling.

Although U-values provide a useful global measure of thermal transmittance, the present study prioritizes detailed numerical evaluation of temperature distribution and heat transfer behavior. Future studies may complement this approach by calculating and comparing U-values for all envelope configurations.

6. Conclusion

One sustainable building material is natural stone. With its available variety of natural colors, structures, and textures, it is suitable for almost any application. Builders can use natural stone in many ways to offer an unlimited number of options to suit style, ambiance, or appearance. It can also be cut into almost any shape or size. Natural stone can meet almost any building need. Using natural stone for facades is extremely cost-effective. Buildings with natural stone facades also have significantly lower heating requirements. Natural stone facades offer notable advantages in terms of energy efficiency, heating requirements, maintenance, and production costs. As a result, as compared to other building materials, it offers substantial environmental advantages due to its durability and dependability. Using natural stone as a building material is a wonderful approach to lower the embodied carbon associated with buildings as sustainability becomes a greater concern in architecture. Because natural stone has a higher amount of thermal mass and requires less energy to produce, it can improve indoor climate regulation, save operating costs, and preserve structural integrity for longer. For sustainable buildings, architects should take into account the timeless beauty of natural stone as well as its sustainable qualities. In this study, a sample building and building envelope were designed considering the climatic conditions of the Black Sea Region. Five different natural stones (Niğde marble, Çamardı marble, Kayseri travertine, Konya andesite, and Giresun granite) were used as wall cladding materials on the outermost layer of this building's envelope. Three diverse wall kinds (sandwich, internally insulated, and externally insulated) were created with 108 alternative scenarios using alternative building materials (concrete blocks, bricks, and aerated concrete) and insulation materials (rock wool, EPS). Temperature distributions throughout the building envelope were evaluated for the 108 alternative scenarios using analyses performed with the ANSYS software package. It was observed that the exterior cladding layer added to the building envelope contributed positively to energy efficiency in all cases. Parallel to the increased insulation, energy consumption, emission release, and, consequently, energy usage costs decreased. It has been determined that the use of natural stones in the Black Sea Region in the construction of energy-efficient buildings that are compatible with the climate and provide ecological and economic benefits would be advantageous. The use of Niğde marble as a cladding material will have more positive effects on healthier alternatives in buildings designed with green building-friendly materials in the Black Sea Region in Turkey.

The apparent difference between the optimal materials identified through ANSYS simulations and the AHP analysis reflects the context-dependent nature of material selection. While Niğde marble provides superior performance in terms of building envelope energy efficiency, Giresun granite emerges as the optimal choice when mechanical strength and long-term durability are prioritized. This distinction highlights that material superiority is not absolute but rather depends on the specific performance objectives of the design problem.

It is crucial to note that this ranking is a function of the assigned criterion weights. A decision scenario prioritizing energy efficiency would involve significantly increasing the weight for thermal conductivity and density, potentially making Çamardı marble or Niğde marble more competitive. Similarly, for a purely decorative, nonstructural interior application, the weights for mechanical properties could be reduced, altering the ranking.

The second part of this study demonstrates the efficacy of the analytical hierarchy approach in providing a systematic and transparent framework for complex material selection problems. It offers a validated, quantitative decision model for natural stone selection that can be adapted to specific project requirements by adjusting the criterion weights. The analysis conclusively identifies Giresun granite as the optimal choice when considering the combined trade-offs between thermal, mechanical, and durability features, with an emphasis on long-term structural performance.

The AHP highlights that a material's superiority is not absolute but is contingent upon the specific priorities of the application. The stark difference in ranking between Giresun granite and Niğde marble underscores the critical distinction between a high-strength, durable material and one suited for applications where thermal buffering is the primary concern.

The aim is for the results of this study to inform decision-makers on this subject and for natural stones to be consciously evaluated in new designs in the Black Sea Region.

Ethical Statement

This study does not contain any studies with human or animal subjects performed by any of the authors.

Conflicts of Interest

The authors declare that they have no conflicts of interest to this work.

Data Availability Statement

Data are available from the corresponding author upon reasonable request.

Author Contribution Statement

Figen Balo: Conceptualization, Methodology, Validation, Formal analysis, Investigation, Resources, Data curation, Writing – original draft, Writing – review & editing, Visualization, Supervision, Project administration. **Ünal Yılmaz:** Software.

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