International Journal of Innovative Engineering Applications

Journal homepage: https://dergipark.org.tr/ijiea

EVALUATION OF THE ENERGY PERFORMANCE OF ADOBE STRUCTURES CONSTRUCTED USING MODERN TECHNIQUES FOR A SUSTAINABLE FUTURE: THE CASE OF ELAZIĞ

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Abstract

Original scientific paper

Natural materials offer significant advantages in terms of energy efficiency in buildings. Materials such as earth, adobe, and stone stand out due to their high thermal mass, which enables them to provide cooling during the summer and retain heat during the winter. Among these natural materials, earth-derived materials are also notable for their low energy costs. This research evaluates the energy performance of a building constructed using the rammed earth technique in the Keban district of Elazığ. As a case study, the "Women's Education and Production Center Project," designed and implemented by Architect Özgül Öztürk in the Keban district of Elazığ, is examined. Comparisons are made with the energy performance that would result if the same building were constructed using concrete and sandwich panel materials. This study aims to analyze the energy performance of rammed earth, concrete, and sandwich panel materials and to determine the environmental impacts of these materials. In this context, the study focuses on alternative materials that could contribute to future sustainable construction. In this research, energy performance analysis was conducted using Revit. This program examined the thermal insulation capacities and energy consumption rates of buildings constructed with different materials. The results of the study indicate that rammed earth material is superior in energy efficiency. These evaluations also highlight the contributions of natural and breathable materials, such as rammed earth, to the environmental sustainability of buildings. It is considered that such materials could emerge as a sustainable alternative in future construction.

Keywords: *Adobe, breathable material, energy performance, natural material, rammed earth, sustainable material.*

SÜRDÜRÜLEBİLİR BİR GELECEK İÇİN MODERN TEKNİKLER KULLANILARAK İNŞA EDİLEN KERPİÇ YAPILARIN ENERJİ PERFORMANSININ DEĞERLENDİRİLMESİ: ELAZIĞ ÖRNEĞİ

Özet

Orijinal bilimsel makale

Doğal malzemeler, yapıların enerji verimliliği açısından önemli avantajlar sunmaktadır. Toprak, kerpiç ve taş gibi doğal malzemeler, yüksek termal kütleleri sayesinde, yaz aylarında serinlik sağlama ve kış aylarında ise ısı tutma özellikleri ile öne çıkmaktadır. Bu doğal malzemelerden biri olan toprak türevli malzemeler, düşük enerji maliyetleri ile de dikkat çekmektedir. Bu çalışma, Elazığ'ın Keban ilçesinde sıkıştırılmış toprak tekniği ile inşa edilmiş bir yapının enerji performansını değerlendirmektedir. Değerlendirilecek yapı örneği olarak, Mimar Özgül Öztürk'ün Elazığ'ın Keban ilçesinde projelendirdiği ve uyguladığı "Kadın Eğitim ve Üretim Merkezi Projesi" ele alınmaktadır. Aynı yapının beton ve sandviç panel ile inşa edilmesi durumunda ortaya çıkacak enerji performansı ile karşılaştırmalar yapılmıştır. Çalışmanın amacı, sıkıştırılmış toprak, beton ve sandviç panel malzemelerin enerji performanslarını analiz etmek ve bu malzemelerin çevresel etkilerini belirlemektir. Bu bağlamda, gelecekteki sürdürülebilir yapılaşmaya katkı sunacak alternatif malzemeler üzerinde durulmuştur. Araştırmada, Revit ile enerji performans analizi yapılmıştır. Bu program aracılığıyla, farklı malzemelerle inşa edilen yapıların ısı yalıtım kapasiteleri, enerji tüketim oranları incelenmiştir. Analiz sonuçları, sıkıştırılmış toprak malzemenin enerji verimliliği açısından daha üstün olduğunu göstermektedir. Bu değerlendirmeler ile sıkıştırılmış toprak gibi doğal ve nefes alan malzemelerin, yapıların çevresel sürdürülebilirliğine katkıları da vurgulanmaktadır. Bu tür malzemelerin, gelecekteki yapılaşmada sürdürülebilir bir alternatif olarak öne çıkabileceği değerlendirilmektedir.

Anahtar Kelimeler: *Kerpiç, nefes alan malzeme, enerji performansı, doğal malzeme, sıkıştırılmış toprak, sürdürülebilir malzeme.*

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Received 11 November 2024; Received in revised form 08 April 2025; Accepted 28 April 2025

 Doi: https://doi.org/10.46460/ijiea.1583130

1 Introduction

Rapid urbanization and industrialization worldwide have led to the rapid depletion of natural resources and a significant increase in environmental impacts. Modern construction processes, particularly the intensive use of industrial materials, have resulted in high energy consumption and carbon emissions. The widespread use of concrete, steel, and glass materials has caused high carbon emissions, negatively affecting the environment. This situation has adversely affected the balance of global ecosystems and made the necessity for sustainable construction even more pressing [1]. In this context, the importance of sustainability in the construction industry has increased and continues to grow globally. The environmental impacts of material choices in the construction sector and energy efficiency are at the heart of global sustainability discussions. As a result, the rapid depletion of energy resources and increasing environmental degradation have brought natural materials back into focus. The concept of sustainability not only requires the conservation of natural resources but also calls for solutions that enhance energy efficiency and ensure the preservation of ecological balance in the future.

Compared to industrial materials, natural materials such as earth and adobe require less energy during production and minimize carbon emissions. The ability of these materials to be safely returned to nature without causing harm and their lack of negative environmental impact presents a significant advantage for the construction sector. Furthermore, these materials are biologically biodegradable and minimize waste production. These characteristics further emphasize the necessity of using earth-derived materials in sustainable construction processes.

Earth-derived materials are significant among sustainable building materials due to their structures, which minimize environmental impacts and have low energy consumption. Materials such as adobe and rammed earth, part of traditional construction techniques, are re-evaluated in modern construction processes. Thanks to their high thermal mass, these materials help balance indoor temperatures, reducing energy consumption. By providing cooling in the summer and retaining heat in the winter, these materials increase the energy efficiency of buildings while keeping energy consumption at a minimum [2]. Furthermore, using local resources for earth-derived materials reduces transportation costs and diminishes environmental impacts. These properties make earth-derived materials a significant alternative for ecological sustainability in modern construction. In this context, the importance of environmental and contemporary adobe applications is increasingly recognized.

In Turkey, industrialization and urbanization have led to a decline in the use of natural materials, resulting in the widespread adoption of industrial materials. Materials such as concrete and steel are commonly preferred in construction but create negative environmental impacts. This situation has led to issues related to energy efficiency and ecological sustainability, emphasizing the need to re-evaluate natural materials. Materials such as earth and adobe, which hold significant importance in Turkey's architectural history, have been overlooked in modern construction processes but should be reconsidered, especially in terms of energy efficiency and environmental sustainability. Elazığ serves as an important example in this regard. With its rich cultural and architectural heritage, Elazığ has long been known for buildings constructed with natural materials by various civilizations throughout history. The environmentally friendly materials used in these buildings, such as adobe and rammed earth, are essential to the city's architectural identity. However, in modern construction processes, industrial alternatives have replaced these materials, leading to a construction approach that is distant from sustainability. In future sustainable construction projects, re-evaluating these traditional materials is critical to preserve the historical identity of cities and build energy-efficient structures with low environmental impact.

The literature contains some studies related to ecological, next-generation adobe. In their research, Leblebiciler and Akıncı addressed this topic, aiming to enhance the quality of ecological adobe production by adding various reinforcing materials to adobe. In their studies, they showed that an adobe sample containing 6% pumice, 10% plaster, 2% slaked lime, 10% volcanic tuff, and 3% organic fibers (flax) exhibited a pressure strength increase from 1075 pascals to 5532 pascals. Its thermal conductivity coefficient decreased from 0.64 W/mK to 0.42 W/mK compared to a sample of pure earth. These findings indicate that contemporary ecological adobe has high-pressure strength and, with its low thermal conductivity, can be used in modern buildings as a next-generation material [3]. Akbaş et al. thoroughly examined adobe construction techniques in their study and subsequently evaluated adobe based on the criteria of national and international certifications related to sustainability and ecological materials. In this context, a detailed table was created to assess the extent to which adobe meets these certification criteria. The researchers argued that adobe should be included in the "green material" category and conducted a comprehensive discussion [4]. Coşkun aimed to develop an alternative to the widely used alker pounding technique in modern technology by utilizing gypsum-added adobe for wall construction in his study. In this context, an experimental study assessed the applicability of the sprayed concrete technique, commonly used in concrete, for gypsum-added adobe materials regarding compressive strength [5]. In his study, Yardımlı investigated contemporary adobe structures within environmental approaches, analyzing how some of these eco-friendly buildings utilize the advantages of adobe material while others do not. He emphasized the ongoing need to explore environmentally sustainable materials and highlighted the ecological benefits of adobe constructions. He also suggested that alternative methods should be explored for recycling and utilizing waste materials [6]. Akkaş's study focuses on using adobe as a sustainable building material. It is emphasized that adobe can be utilized in masonry structures and as panel walls in reinforced concrete and steel structures. Through experimental investigations, suitable additives and curing conditions have been determined to increase the mechanical strength of adobe, and the results suggest that a wider potential for its use in the construction sector has been demonstrated [7]. In the study, Kıvrak investigates the effects of silica fume on adobe material's mechanical and physical properties. The clay soil was mixed with silica fume to produce adobe. The results of the experiments suggest that adding silica fume positively impacts all properties of the adobe [8]. Koç examines the role of earth materials in ecological design to reduce the impacts of increasing urbanization on the environment. It is emphasized that excavation soil should be utilized in construction, and earth construction techniques and regulations from different countries are compared. The study presents recommendations for Turkey's development of new earth construction regulations [9]. Binici et al. investigated the reasons behind the collapse of rubble stone and adobe structures with earthen mortar during the 2010 Elazığ earthquake. It is noted that heavy stones contributed to fatalities during earthquakes and that using fiber-reinforced adobe could reduce the extent of damage. The study examines the engineering properties of adobe enhanced with plastic and textile fibers, pumice, gypsum, and cement and finds that fiber-reinforced adobe possesses economic, energy-saving, and improved mechanical properties [10]. In his study, Ataç investigates the integration of adobe material with biomaterials in sustainable architecture. Compressed earth structures are associated with digital design and mycorrhizal fungi, exploring the contribution of bioengineering and construction disciplines to architectural design processes [11]. Yavaş, in his study, addresses the history, physical, and mechanical properties of adobe material, aiming to reassess this material in terms of earthquake safety. He particularly critiques the 2018 Turkey Building Earthquake Regulation, which does not permit adobe buildings, and offers recommendations for including adobe structures in the regulations with certain limitations. The study provides a detailed examination of the calculations related to the structural safety of adobe buildings and earthquake safety standards [12]. In their study, Binici et al. found the earthquake resistance of limestone used in rural areas of Turkey inadequate. They investigated the mechanical properties of materials to be used in adobe production. The study argues that using waste materials such as fiber, wheat straw, polystyrene, pumice, and clay in adobe production provides economic benefits, energy savings, and improved mechanical properties [13]. As for Özgünler, in his study, he emphasizes that the high energy consumption of the construction industry contributes to global warming and discusses the importance of environmentally friendly renewable energy sources and sustainable building materials. By stating that traditional earth-based materials are produced with low energy and are environmentally friendly, he has conducted laboratory studies on the sustainability of these materials. The study highlights the ecological values of earth-based building materials and their potential to ensure rural sustainability [14].

In the studies reviewed in the literature, no research has been found that analyzes, with numerical data, the potential for adobe structures built using modern construction methods to exhibit better energy performance compared to contemporary building materials. Therefore, this paper provides a unique contribution compared to other studies in the literature. The study analyzed the energy performance of an ecological adobe building using a simulation program. Additionally, the performance of this building was simulated in comparison to reinforced concrete and container structures. Based on the obtained numerical data, it was concluded that adobe structures built with modern construction techniques could demonstrate better energy performance compared to other materials commonly used in the construction industry.

2 Sustainable Material: Adobe

In recent years, sustainability has gained more importance due to increasing environmental pollution and the conservation of energy resources. Numerous institutions, councils, and agencies have conducted studies to explain this concept. These studies suggest that "Sustainability is the continuity of systems and processes" [15].

The concept of sustainability is also of great importance in the construction process of buildings. In the construction sector, while environmental pollution increases, the conservation of energy resources should be a primary goal. Sustainable building materials are composed of components that do not pose a risk to human and environmental health and can be recycled and reused [16]. Sustainable building materials minimize energy consumption during production and use, and they are materials that do not pose a risk to the environment or human health from waste generated during raw material production, processing, use, maintenance, and repair stages [17]. The building materials are expected to be high-quality, environmentally friendly, aesthetically pleasing, and cost-effective. Additionally, materials that do not harm human health should be preferred.

With the advancement of technology, new construction materials have started to be preferred over earth and earth-derived materials, which have been used for long periods. Despite this, earth and earth-derived materials continue to be used in many areas. To this day, earth has primarily been utilized as adobe, a building material.

Figure 1. Earth (Adobe) Building Example [18].

Adobe is one of the world's oldest and most widely used building materials. Due to its accessibility and ease of processing, people have preferred this material since ancient times. The environmental impact of adobe is minimal [19].

Figure 2. Regions where Adobe is widely used around the world.

Adobe has many advantages and disadvantages.
Advantages:

- Its porous structure helps maintain the humidity levels of the interior space.
- It regulates heat and moisture balance through its thermal insulation properties.
- Storing heating energy contributes to maintaining a stable temperature for extended periods.
- Low production cost and the absence of the need for specialized facilities make it an economical option.
- It does not require mechanical energy during production and use stages.
- It is a recyclable material that does not harm the environment.
- Using earth obtained from excavation reduces transportation costs.

Disadvantages:

- It has high water sensitivity.
- It has low compressive strength.
- It requires annual maintenance.

All these properties make adobe a cost-effective and environmentally friendly option [5].

Adobe is a natural and healthy building material and stands out as an important construction material that contributes to preserving the global ecological balance and energy savings during both its production process and usage phase. In this context, adobe is a sustainable building material.

With its ability to regulate indoor air comfort, heat retention properties, and breathability, Adobe provides users with a refreshing living space. However, over time, it has faced tough competition from contemporary production techniques and has struggled to replace the energy-intensive reinforced concrete construction method. This situation poses risks regarding sustainable construction techniques and the preservation of cultural heritage for future generations [4].

It is essential to consider adobe as a prominent option among contemporary building materials to address the risks posed by this situation. The disadvantages of adobe must be minimized, and its advantages should be optimized more effectively.

There are two main approaches to using adobe in building construction: traditional and contemporary. Traditional adobe construction methods include the rammed earth technique and adobe block production. The rammed earth method involves the manual shaping of a damp earth mixture, combined with straw or plant fibers, without molds; this process allows for forming organic geometries. On the other hand, adobe block production involves pouring the earth mixture into molds and allowing it to dry in the sun, resulting in durable blocks. Among the contemporary adobe construction methods are rammed earth blocks, the tamping method, the spraying method, the holistic construction technique, and the unit construction technique. Rammed earth blocks are structural elements obtained by compressing a low-water mixture under pressure. The tamping method is based on mechanically compacting the earth mixture, while the spraying method involves surface coating using specialized machines. The holistic construction technique increases material efficiency by combining tamping and rammed earth methods, while the unit construction technique facilitates the construction of modular structures [6], [21].

In this context, considering earth materials in different forms and enhancing their water resistance have been crucial steps in meeting user expectations, thus contributing positively to the widespread adoption of earth materials in the future, particularly in terms of sustainability [4]. Adobe, through its use in various forms of earth materials and its application with more contemporary construction techniques, has gained characteristics that make it preferable as a modern building material. Alker is one of the most popular Adobe forms today. Alker is the process of reinforcing traditional adobe by adding plaster.

When lime is added to traditional adobe material, the water absorption rate of the material decreases, preventing the material from disintegrating due to the effect of water. Additionally, the setting time of the plaster is extended, and the workability of the mixture is improved. The addition of plaster to traditional adobe prevents the material from undergoing shrinkage. The evaporating water leaves space for air pockets, enhancing the adobe material's heat storage capacity [2].

Alker delivers the expected performance efficiently with its water absorption, heat storage, and other physical properties. The rapid setting of plaster in alker prevents deformation, shrinkage, and cracking that may occur during clay drying while also enhancing compressive strength [2].

3 Materials and Methods

In this research, the necessity of sustainable materials, the importance of adobe and natural building materials, contemporary adobe techniques, and the rationale for the use of different forms of these materials are explained in detail.

Subsequently, the "Women's Education and Production Center Project" designed and implemented by Architect Özgül Öztürk in Keban is explained in detail through a practical application of how energy performance analysis is conducted using Autodesk Revit software. For energy performance analysis, the building to be analyzed in this study was selected, and one of the calculation methods, Revit software, was utilized to obtain the necessary calculations. Based on the analysis provided by the software, the building's annual cooling and heating loads are calculated. Additionally, to validate the accuracy of the analysis, heat gain and heat loss calculations were made using the relevant formulas to determine the building's annual cooling and heating loads, and a verification process was carried out with the obtained results.

In the final stage of the energy analysis, separate analyses were conducted for alternative materials, such as non-natural concrete or sandwich panels, to assess how the energy performance of the building would change if these materials were used instead of the rammed earth material. The analysis results were compared, and based on these comparisons, the necessity of sustainable materials, the importance of rammed earth and other natural building materials, contemporary rammed earth methods, and the reasons for using different forms of these materials were highlighted.

3.1 Building Analysis

In this study, the energy performance of the Women's Education and Production Center, an ecological building example constructed using the compressed earth technique in the Keban district of Elâzığ as part of the "Anadolu Meleği" project by Architect Özgül Öztürk, is being examined.

3.1.1 Women's Education and Production Center Project

The Women’s Education and Production Center is an ecological architectural example realized by architect Özgül Öztürk within the framework of the "Anadolu Meleği" project. This project was initiated following Öztürk’s winning of the first prize in the 2016 "Women of the Earth" competition, organized by the Yves Rocher Foundation and the French Institute. The project aims to revitalize rural architecture and create an environmentally friendly structure utilizing natural materials. Furthermore, this building cooperates with women’s educational and production processes [22]. The structure has been constructed using the compressed earth technique. This technique is evident in the exterior images presented in Figure 3.

Figure 3. Exterior forms of the building.

This ecological building, constructed in Keban in 2019, aims to increase women’s participation in production processes by combining local architectural elements with modern ecological techniques. The short-term goals of the project are to support natural life, facilitate women’s social and economic participation, and transform rural areas into attractive centers. In the medium term, the development of ecotourism is targeted, while in the long term, the project aims to promote women’s entrepreneurship and enhance economic activities in rural areas [22].

Figure 4. Interior forms of the building [22].

The building is a single-story structure with five windows and one fireplace. The entrance door and windows are made of wood, with a preference for using natural materials. Immediately to the left of the entrance is a kitchen counter, and a cabinet used for storage is directly opposite the entrance. Inside are seating areas designed in a divan style and made from recycled materials. The lintels, located at the upper level of the windows, provide structural support to the building. At the same time, the materials used in the interior are observed to possess warm and breathable characteristics (Figure 4).

3.1.2 Creating the Structure in Revit and Energy Analysis Settings

Autodesk Revit is an object-based software grounded in three-dimensional modeling techniques. This program is used for the design of buildings. It digitally presents the physical and functional characteristics of the designed structure and then stores this information for future use. This information repository can be accessed by all disciplines [23]. Based on this data, energy performance analysis of these designs can be conducted using the program. Users can optimize building designs based on the program's output, and necessary adjustments can be made in the digital environment by considering environmental impacts before the designs are constructed.

For the analyses performed in Revit software to yield accurate results, the building model must be created entirely and precisely. The properties of the materials used in the design must be thoroughly defined in the software, thereby preventing any potential errors or deficiencies in the analysis results [24].

In this context, after the plan drawings of the building, whose measurements have been taken (Figure 5), were completed, a detailed modeling process was carried out using Autodesk Revit software to conduct an energy performance analysis.

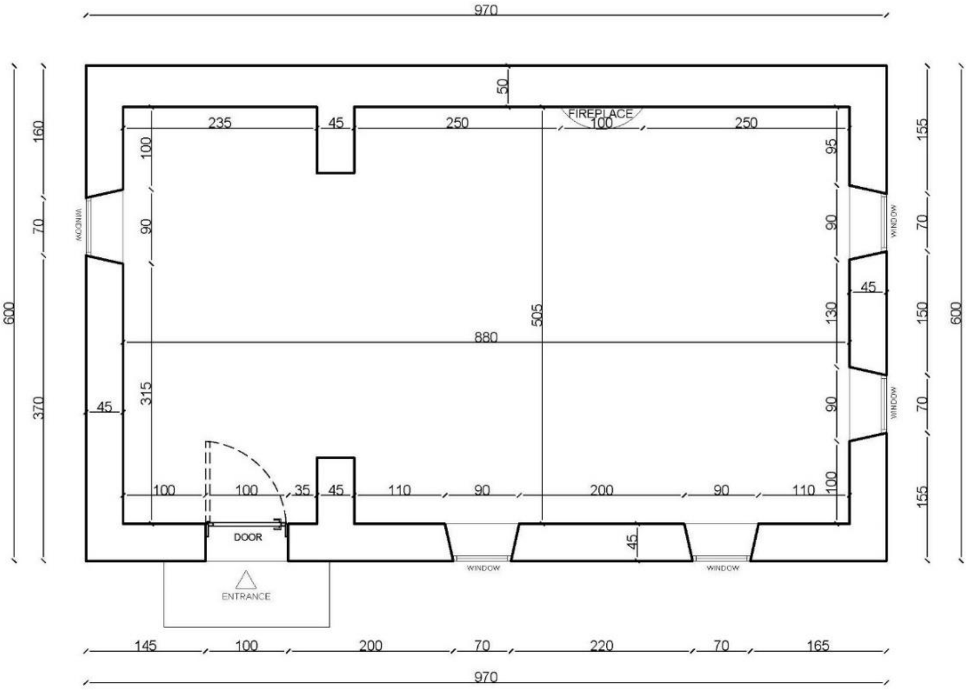

figure 5. Architectural plan of the building.

The current condition of the building and all architectural details were created through three-dimensional modeling in the digital environment (Figure 6). This enabled the analysis and evaluation processes to be conducted based on the building's digital model.

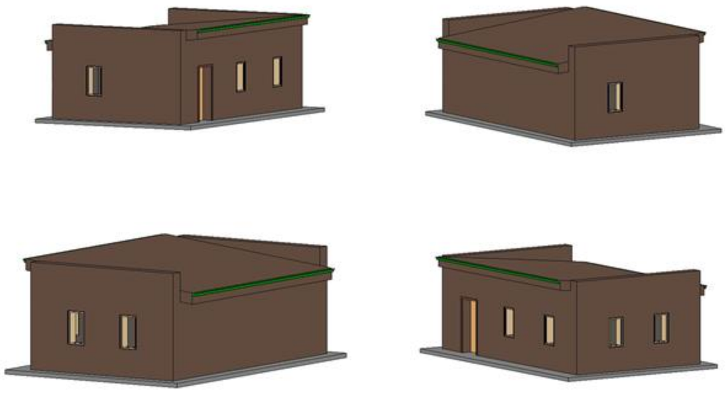

Figure 6. Three-dimensional model of the building created with autodesk revit.

In this process, the properties of the materials used in the building were defined in detail and comprehensively in the program using intelligent objects (Figure 7). This operation was carried out to obtain accurate and reliable results in the energy analysis [25].

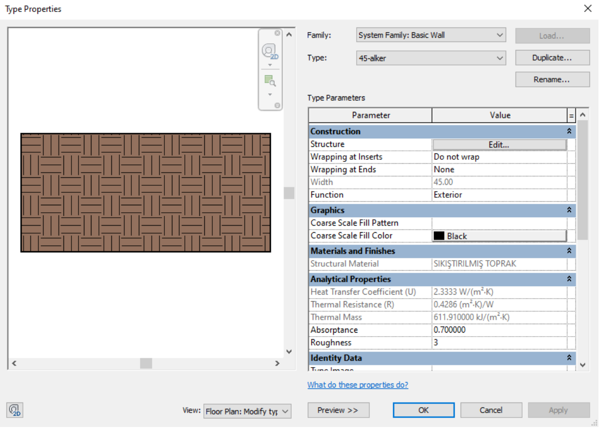

Figure 7. Building exterior wall layers detailed modeling window.

The U-values for each building component are pre-defined in the program and can be adjusted by the user when necessary (Figure 8). This allows for the integration of energy performance values appropriate to the building layers during the modeling process [25].

Mutlu's study specifies the rammed earth's thermal conductivity coefficient (λ) as 1.05 W/mK (Figure 8). In this project, based on the data obtained from the mentioned study, the thermal conductivity coefficient of rammed earth has been assumed to be the same value [26].

Additionally, two different models were created to compare natural and artificial materials, assuming that the buildings were designed with non-natural materials instead of earth-derived materials. In the first model, the building walls were created with layers consisting of 3 cm plaster, 20 cm reinforced concrete, and 2 cm plaster. In the second model, the walls were structured with layers of 0.5 cm aluminum sheet, 4 cm XPS, and 0.5 cm aluminum sheet. The energy performance analyses for both models were conducted using the Revit program.

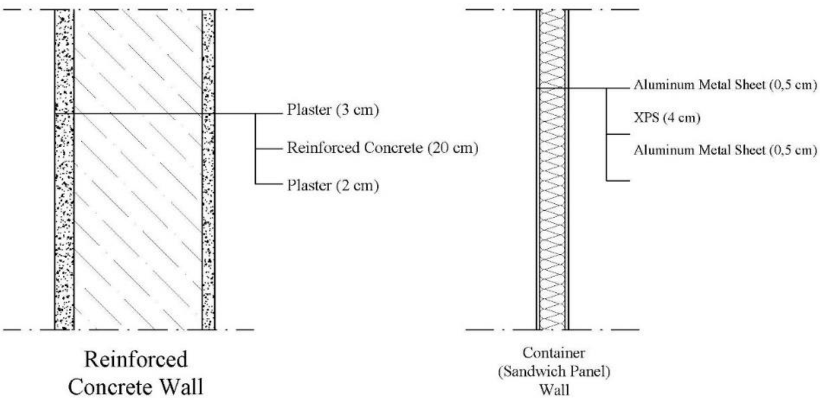

Figure 8. Wall sections for the case of designing the building with non-natural materials.

The materials' thermal conductivity coefficients (λ) for these two models are provided in Table 1 below, based on the data obtained from TS 825 and Balcıoğlu's study [27], [28].

Table 1. Thermal conductivity coefficients (λ) of the building materials used in the models [27], [28].

Building Material	Thermal Conductivity Coefficient (λ)
Plaster	1,60 (W/mK)
Reinforced concrete	2,50 (W/mK)
Aluminum	204 (W/mK)
Extruded Polystyrene Foam (XPS)	0,030 (W/mK)

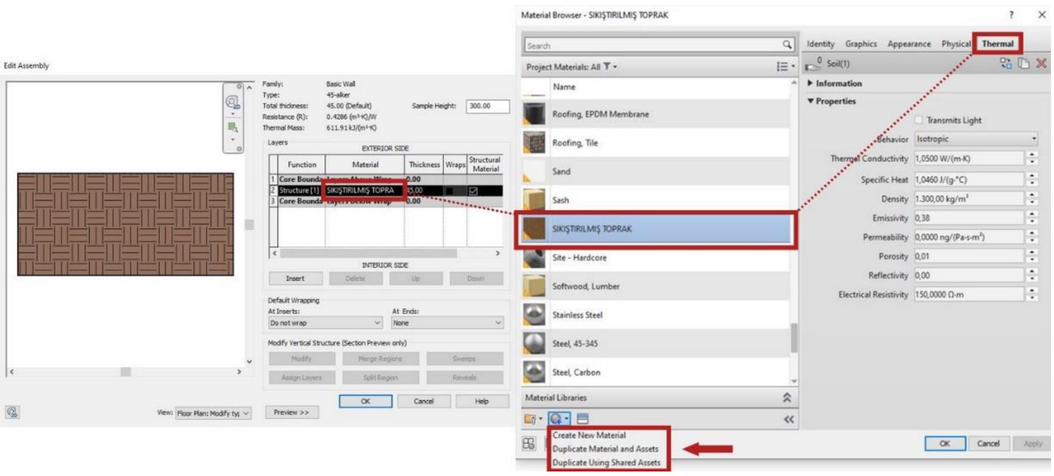

Figure 9. Creation of the detailed building model in Revit, showing the building component layers and thermal properties.

Materials not available in the software can be added using the "Create New Material" option, or a new material can be created by duplicating the properties of existing materials with the "Duplicate" option (Figure 9). In this study, since the building material for the energy analysis is not included in the material database, the materials were explicitly defined and added to the model.

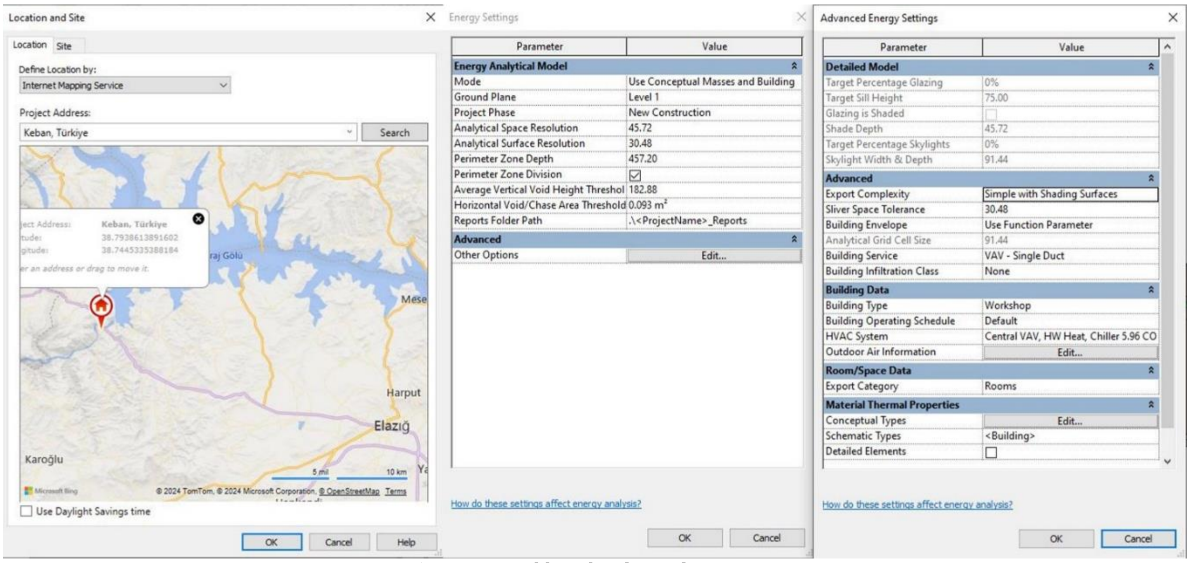

Figure 10. Building details window in revit.

After the model was created, energy definitions were made in the Revit software. In the "Analyze" tab, parameters such as the building's location, type, and daily usage range were defined, and the necessary adjustments were made to ensure that the energy analysis would provide accurate results (Figure 10).

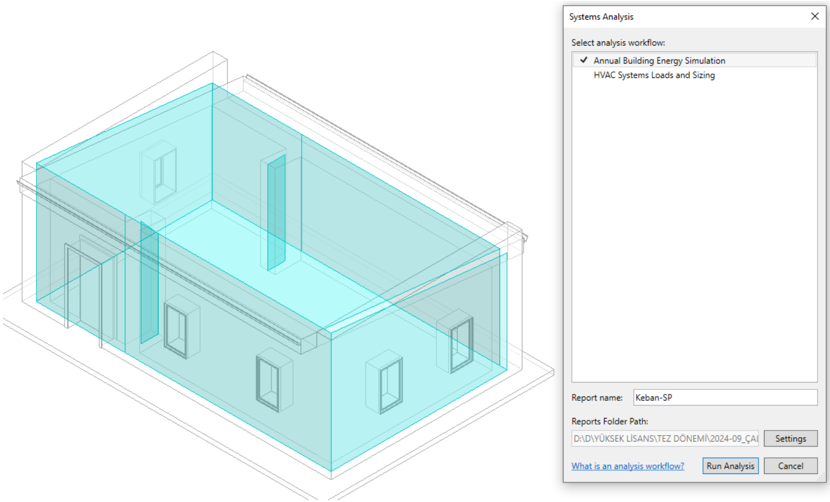

Figure 11. *Analysis window in revit.*

In the final step, by clicking on the "Systems Analysis" option in the "Energy Optimization" toolbar under the "Analyze" tab, selecting "Annual Building Energy Simulation," and then giving the "Run Analysis" command, the software performs the building energy analysis (Figure 11).

3.2 Validation Study

The building's annual cooling and heating loads were calculated using the relevant formulas for heat gain and heat loss to validate the results of Autodesk Revit software. A verification study was conducted by comparing the results obtained from Revit with these calculations.

The thermal conductivity values and other data obtained from the literature were used in the accuracy study of the research. Koçu's study states that adobe structures with wall thicknesses ranging from 50-70 cm in cold climate regions meet the required thermal conductivity coefficient of U = 0.50 W/m²K, as specified in the TS 825 standard [29]. Daily heat losses and gains were calculated by processing the areas of building component surfaces, lighting, appliance information, and user numbers; the thermal conductivity coefficients of building elements; and the "U" values of windows and doors into the "Microsoft Excel" program, using relevant formulas.

The required climate data were obtained from the Turkish State Meteorological Service website, and the relevant data are shown in Table 2.

Table 2. Heating and cooling degree days for the Keban district of Elaziğ in 2023 [30].

Centre	D/D	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
ELAZIĞ KEBAN (2023)	HDD	469	466	241	140	14					6	176	355	1867
	T≤15 °C	31	28	31	23	3					2	23	31	172
	CDD						66	211	276	107				660
	T>22 °C						25	31	31	28				115

(D/D = Degree-Day, HDD = Heating Degree-Day, CDD = Cooling Degree-Day, T≤15°C = Number of days with temperature ≤15°C, T>22°C = Number of days with temperature >22°C).

Heating Degree Days (HDD) measure the severity of cold weather conditions during a specific period, considering the outdoor and indoor temperatures. Cooling Degree Days (CDD) determine the severity of hot weather conditions, considering only the outdoor temperatures. These calculations are based on threshold temperatures of 15°C for heating and 22°C for cooling [31].

The results obtained in the verification study are presented in Table 3.

Table 3. Daily heat loss and gain.

Daily Heat Loss	2.993 W
Daily Heat Gain	5.796 W

The daily heat loss of 2,993 W represents the energy exchange with the outdoor conditions, while the daily heat gain of 5,796 W represents the energy inputs from both the indoor and outdoor environments of the building. These values are used to calculate the annual heating and cooling loads.

After the heat gain and heat loss values are determined in watts (W), they need to be converted to kilowatt-hours (kWh) to calculate the annual heating and cooling loads (kW=W/1000). Then, the energy amount in kilowatt-hours (kWh) is calculated by multiplying the power (kW) by the time (in hours) (kWh=kW×hour). In this calculation process, the heating and cooling degree days for the year 2023, shown in Table 2, are taken into account, with 172 days assumed for the heating system and 115 days for the cooling system. Additionally, a daily usage duration of 9 hours is considered for both systems. The calculation made based on these values is shown in Table 4.

Table 4. Annual heating and cooling loads calculated from the data obtained from heat loss and gain.

Annual Heating Load Required	4.633 kWh
Annual Cooling Load Required	5.999 kWh

Table 4 presents the annual heating and cooling loads calculated based on heat loss and gain. The annual heating load has been determined as 4,633 kWh while the annual cooling load is 5,999 kWh.

Table 5. Difference between Annual Cooling and heating loads.

	With the Formula-Based Calculation Method	With Revit	DIFFERENCE (Percentage)
Annual Heating Load Required	4.633 kWh	4250 kWh	% 9.01
Annual Cooling Load Required	5.999 kWh	5625 kWh	% 6.65

Table 5 presents the findings obtained from the heating-cooling load analysis and total loads, compared with the results derived from the Revit software. In this context, the small difference in kWh confirms the accuracy and validity of the calculations. This supports the reliability and precision of the applied analysis methods.

4 Findings and Evaluation

The building was modeled using Revit software, and the necessary analysis settings were input to perform the required analyses.

Table 6. Annual and maximum values (rammed earth - current state).

	Annual Value (kWh)	Maximum Value (W)	Day of Maximum Value
Heating	4250	9973	11 JANUARY
Cooling	5625	4375	20 JULY
Total Energy Load of the Building	9875		

Table 6 presents the annual energy consumption and maximum energy loads of a building constructed using rammed earth. The building consumes 4250 kWh of energy annually for heating and 5625 kWh for cooling. The maximum energy demand for the heating system occurred on January 11, reaching 9973 W. This indicates that the low temperatures in the winter months increase the heating load. The highest demand for the cooling system was recorded on July 20, with a value of 4375 W. The hot weather conditions during the summer months increased the building's cooling needs, and this load coincided with the hottest hours of the day. In total, the building consumes 9875 kWh of energy annually.

Similarly, the building's heat gain and heat loss calculations were performed using the relevant formulas in Excel, and based on these data, the building's annual cooling and heating loads were determined.

Furthermore, as a result of the analyses conducted for the comparison of natural and artificial materials, the results obtained for the building designed with reinforced concrete are presented in Table 7, while the results for the building designed with container (sandwich panel) are provided in Table 8.

Table 7. Annual and maximum values (in the case of reinforced concrete).

	Annual Value (kWh)	Maximum Value (W)	Day of Maximum Value
Heating	4966	11008	11 JANUARY
Cooling	6847	5363	01 AUGUST
Total Energy Load of the Building	11813		

Table 7 presents the annual energy consumption and maximum energy loads of the building, assuming it is constructed using reinforced concrete materials. The building consumes 4966 kWh for annual heating and 6847 kWh for cooling. The maximum energy demand of the heating system was recorded as 11008 W on January 11th. The highest demand for the cooling system occurred on August 1st, with a value of 5363 W. In total, the building consumes 11813 kWh of energy annually.

Table 8. Annual and maximum values (in the case of container construction).

	Annual Value (kWh)	Maximum Value (W)	Day of Maximum Value
Heating	5016	11643	11 JANUARY
Cooling	7053	5487	01 AUGUST
Total Energy Load of the Building	12069		

Table 8 presents the annual energy consumption and maximum energy loads of the building, assuming it is constructed using container materials. The building consumes 5016 kWh for annual heating and 7053 kWh for cooling. The maximum energy demand of the heating system was recorded as 11643 W on January 11th. The highest demand for the cooling system occurred on August 1st, with a value of 5487 W. In total, the building consumes 12069 kWh of energy annually.

The annual heating and cooling loads and the annual energy consumption for different building materials are presented together in Table 9.

Table 9. Annual heating and cooling loads and annual energy consumption of the same building using different building materials.

	Annual Heating Load (kWh)	Annual Cooling Load (kWh)	Total Annual Energy Load (kWh)
Rammed Earth	4250	5625	9875
Reinforced Concrete	4966	6847	11813
Container (Sandwich Panel)	5016	7053	12069

The natural building material, rammed earth, records a total energy consumption of 9875 kWh with lower heating (4250 kWh) and cooling (5625 kWh) loads, while reinforced concrete and container structures show higher energy consumptions of 11813 kWh and 12069 kWh, respectively, exhibiting lower efficiency compared to natural materials. These data clearly indicate that natural materials are more advantageous in terms of energy efficiency. The analysis shows that buildings designed with industrial materials such as reinforced concrete and sandwich panels, as opposed to natural materials, exhibited higher energy consumption during heating and cooling periods, based on wall thicknesses determined according to market standards.

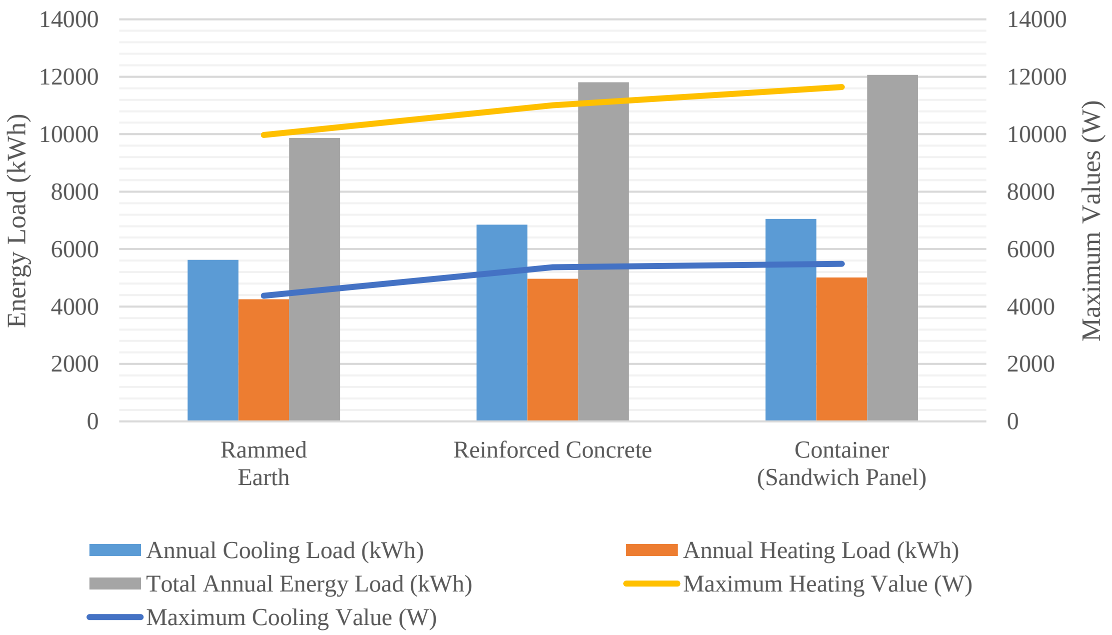

Figure 12. Annual energy load and maximum values.

In addition to the rammed earth material currently used in the structure, the annual heating and cooling load amounts, total annual energy load, and maximum heating and cooling values obtained when reinforced concrete and container materials are used, are collectively presented in Figure 12. As seen, the rammed earth material exhibits the lowest values for both maximum heating and cooling demand. The maximum heating value is determined to be 9973 W, while the maximum cooling value is recorded as 4375 W. In the case of reinforced concrete, the structure demonstrates a higher energy requirement with a maximum heating demand of 11008 W and a maximum cooling value of 5363 W. When constructed with container material, the structure exhibits the highest energy consumption with a maximum heating demand of 11643 W, and the maximum cooling value is measured as 5487 W. These data demonstrate that rammed earth is more advantageous in terms of energy efficiency compared to other materials.

5 Conclusion

The rapidly advancing industrialization process today has led to the widespread use of industrial and non-natural materials in the construction sector. The preference for materials such as concrete, steel, and glass, which consume significant energy and resources, results in high levels of carbon emissions, severely threatening environmental sustainability. These materials increase energy consumption during the production phase and throughout the entire life cycle of buildings, contributing to the deepening of global warming and other environmental issues.

In Turkey, as in the rest of the world, the processes of industrialization and urbanization have led to a shift from natural materials to industrial alternatives. Especially in large cities, reinforced concrete and steel structures have become dominant, resulting in increased energy consumption and adverse environmental impacts. Although Turkey's rich architectural heritage is based on traditional building materials and techniques, modern construction processes often overlook these elements. Particularly in terms of energy efficiency and sustainability, it is essential to reconsider the use of natural materials and integrate them into current building policies. In this context, the study emphasizes, based on the data obtained through literature review, the importance of sustainable materials and the need to readdress issues related to energy efficiency.

Additionally, in the study, the energy performance analysis of a building constructed using contemporary adobe techniques was conducted with the help of Revit software. The findings revealed that earth-based natural materials, such as adobe, offer significant advantages in terms of energy efficiency. The study also calculated the energy performance of the building when designed separately with reinforced concrete and sandwich panel materials, using Revit software. These results were evaluated by comparing them with the building's existing condition. As a natural building material, rammed earth exhibited significantly lower energy loads during both heating and cooling processes, demonstrating clear efficiency in total energy consumption. In contrast, reinforced concrete and container buildings displayed less efficient performance with higher energy consumption compared to natural materials. Furthermore, the study found that the maximum energy consumption levels of buildings constructed with non-natural materials were higher than those built with natural materials. Notably, reinforced concrete and sandwich panel buildings consumed significantly more energy during cooling periods, indicating that these materials are less suitable in terms of energy efficiency. When all the findings were considered, the study concluded that buildings constructed using contemporary adobe techniques could emerge as more energy-efficient, with lower energy requirements in both heating and cooling processes. This highlights the importance of natural materials for environmental sustainability. Additionally, modern adobe applications, such as rammed earth, should be regarded as a healthier and more environmentally friendly alternative to industrial materials.

This research highlights the need for a re-evaluation of natural materials, which have been frequently used in traditional building practices throughout history, in the context of the modern construction industry. In the past, structures built with environmentally friendly materials such as adobe and mud brick have held significant places in the identity of cities. These traditional building techniques not only provided low-cost solutions by utilizing local resources, but also resulted in buildings with high energy efficiency. Based on the findings of this study, it is evident that modern adobe techniques, such as rammed earth, offer a more environmentally friendly and health-conscious alternative compared to industrial materials. The re-evaluation of these materials holds significant potential for constructing sustainable buildings and improving energy efficiency. In this regard, the broader use of natural materials in the construction sector will yield both economic and ecological benefits. Furthermore, it will not only contribute to environmental sustainability but also aid in preserving the historical identity of the city.

In conclusion, this study emphasizes the importance of re-evaluating natural materials (particularly alternatives such as adobe and rammed earth) in the context of the modern construction industry. The advantages of traditional construction techniques in terms of energy efficiency and environmental sustainability should not be overlooked in contemporary building processes. The findings indicate that natural materials provide a more efficient and environmentally friendly option compared to industrial alternatives in terms of energy performance. In this context, the broader adoption of natural materials in the construction sector will contribute to the preservation of the historical identity of cities, offering both economic and ecological benefits. The integration of traditional building materials with contemporary construction techniques will contribute to the creation of a sustainable future, and this process will play a critical role in shaping future building policies.

Declaration

The authors declare that the ethics committee approval is not required for this study.

Acknowledgments

There is no conflict of interest among the authors. Furthermore, we would like to express our gratitude to Architect Özgül Öztürk for her valuable contributions to the realization of this study.

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