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Sustainable and Energy Saving Model Research for Existing Housing Stocks; Field Study

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Abstract: Although buildings constitute 35% of global energy use and 38% of carbon emissions from energy, the amount of energy and energy-related carbon emissions are increasing rapidly. On the other hand, non-renewable usable energy resources are decreasing on the contrary. New buildings are being built due to the increasing population and the existing building stock not meeting the needs or losing its lifespan. Some of the existing building stock is demolished and renewed for structural reasons and some for reasons such as usage performance. It is possible to reduce both energy consumption and greenhouse gas emissions with strategic energy uses in existing building stocks. There are various techniques to measure the maximum performance of sustainable and energy-efficient use of existing building stocks with which changes. Building Information Modeling (BIM) technology is one of these techniques that provides wide opportunities to users in recent years, and it is almost a virtual laboratory of structures. Building stocks can be modeled with BIM, and alternative shell and system suggestions can be used to measure how building performance has changed and to achieve the best results. In this research study, improvement scenarios that optimize energy use in existing building stocks are investigated on a sample residential building by using the virtual laboratory facilities of BIM. After measuring the current energy performance of the existing building with BIM tools, 192 alternative results were obtained with 6 variables (external walls, roof, insulation layers, transparent surface materials, lighting, and photovoltaic panels). The obtained alternatives were compared with the current state of the existing building. The material expenditures and amortization periods required for these alternative scenarios are also calculated. The results obtained were evaluated according to annual / lifetime energy consumption, fuel, electricity, initial investment costs, energy use intensity, and carbon emission amounts. With the optimization of the current situation of the sample building, annual fuel consumption decreased by 61% and electricity consumption by 64%. The amortization period of the optimum improvement was determined as 12 years.

Keywords: Sustainability Architecture; Building Information Modeling; Building Performance Analysis; energy analysis

1. Introduction

Structure; It is a product that has come together with the sub-systems that make it up. The emergence of the structure takes place by building (making). Together with the subsystems that make up the structure, it has a share of 13% of the world economy. The world construction sector economy reached the level of 11 trillion dollars in 2020 [1]. In Turkey, although the budget of the construction sector is around 200 billion dollars, the share of the construction sector in the Gross National Product (GNP) is around 5%; Together with the 250 sub-sectors it is associated with, it constitutes 35% of the GNP [2]. Undoubtedly, the largest share of the construction sector in this economic size is residences. Houses are buildings built to shelter, sleep, and provide privacy, and their history is parallel to the history of humanity. Houses that meet the minimum shelter and protection needs in the early days of history have started to have an important share in non-renewable energy consumption in light of the invention of electricity and developments in electronics and informatics in recent centuries [3–6]. Energy consumption has reached its peak, with the tools and equipment for lighting, heating, cooling, electrical appliances, electronic appliances, smart systems, etc. So; The energy use of the global construction sector is at the level of 35% of the total energy consumption [3–7]. Global warming, rapid consumption and reduction of non-renewable energy resources, drying of dams, droughts, etc. balance changes also cause the search for effective, efficient, and sustainable use of energy in the construction sector [8]. These requirements have led to a century in which new materials and new systems have emerged in the sector, intensive R&D activities both in Turkey and in the world, and solution alternatives have been discussed intensively [9]. Now both the world and Turkey agree on the production of high-performance, environmentally friendly, sustainable, and energy-efficient buildings. Therefore, green building certification systems have been developed in the last 20 years by many organizations and organizations to implement and disseminate sustainable architectural measures in construction projects, to evaluate and monitor building performance, and to gather information to support designer decision-making at different stages of the project [10,11]. Green building certification systems are a kind of rating system that reveals the effects of projects on the environment and scores according to various criteria to protect the environment [12] Some of these systems were developed for use all over the world, while others were developed or adapted to suit the environmental, economic and socio-cultural characteristics of a particular region [10]. certification systems such as SBTOOL, HK-BEAM, CEPAS, SBAT, GREEN STAR, and CASBEE, apart from BREEAM emerged in the UK, and LEED emerged in the USA, which is popularly used in the world [13] Certification systems aim to define and promote sustainable green architecture by creating common standards and developing methods [14]. In our country, there are some legal regulations such as "Energy Efficiency Law", "Energy Performance Regulation in Buildings" and "Energy Identity Certificate" that can initiate and evaluate the design of buildings with sustainable architectural principles, but still, there is no national green building certificate in Turkey yet. no system [15]. It is extremely important that this new understanding and production model be applied in the existing building stock as well as in the new buildings. Because newly constructed buildings (especially residences) are at a very low level compared to the existing stock. For this reason, reducing the energy consumption of existing housing stocks with optimum solutions and renewals, even making them sustainable, is of great importance in reducing the energy share on a global and national scale.

The construction industry does not have a laboratory. The only environment in which the construction and the result of the construction are tested is the situation in which the product is physically revealed, which is also irreversible. At this point of insolvency, the "Building Information Modeling" technology, which has been offered to the construction industry through technological developments in recent years, offers us the opportunity to test and analyze in a virtual environment without making the building [16]. In a sense, it is the digital expression of both the physical and functional properties of the building, both during the construction phase and in its life cycle [17]. With the cooperation of smart object-based parametric models that can be made with BIM and add-on software tools that can be used with this software, it is possible to make smart models of existing building stocks, make energy performance analyses and establish different scenarios with alternative suggestions [17,18] In an advanced stage, it is possible to compare the alternative scenarios created with the existing structure and to evaluate the positive and negative results [19,20]

In this research, the usability of existing housing stocks to improve energy performance with the help of BIM technology and add-on software has been investigated and the most appropriate solutions have been revealed. A sample residential building was selected for the study and the current parameters and location data of the house were modeled with the BIM software Revit. The current state of the created model was analyzed with the Green Building Studio (GBS) plug-in software. After the current situation analysis, 192 alternative scenarios were created with 6 variable parameters, energy analyzes were made separately according to each scenario created and comparisons were made. Obtained results; Results were obtained according to annual energy and fuel consumption, annual and lifetime costs, energy use intensities, and carbon emission values. To examine the feasibility of these models under real conditions and conditions, the construction costs

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were calculated and the amortization periods were determined. While conducting this research, the parameters of the structural and structural features of the existing housing stock, its performance against natural disasters, and whether the building meets the usage needs under current conditions were excluded from the scope.

2. Literature Review

In a study conducted on a three-story residence, the effect of building orientation on energy consumption was investigated with Revit and GBS software, and it was concluded that the correct building orientation provides substantial energy savings in the building life cycle [21].

Abhinaya et al. After modeling and analyzing the current situation of the two-story house with Revit, it compared it with the existing building by using green material alternatives in its walls, roof, floor, and windows, and observed that its energy performance increased significantly. With this observation, he emphasized the importance of BIM tools in predicting and making decisions and preventing possible errors [22].

Ahsan et al. investigated the effect of passive cooling on annual energy consumption in an existing university building with Autodesk Ecotect software. Comparisons were made with parameters such as suitable thermal insulation techniques, lighting selection, façade transparency ratio, and selection of alternatives of glass materials. As a result, they concluded that the 38-month energy consumption of the building could be reduced by 35% [23].

Kim et al. To investigate the effect of the location and size of the windows in the buildings and the direction of the building on the total energy consumption of the building, he researched a two-story residence. With the help of Revit and GBS software, 65 different scenarios were developed over alternative parameters and it was revealed that the facade transparency rate and energy consumption are directly proportional, and the energy consumption of the building is minimized when the windows are located at mid-height in all directions [24].

Lim et al. investigated two sample buildings in the eastern province of Saudi Arabia as a techno-economic solution research for the renewal of existing housing stocks. In the study, they proposed a 3-stage energy improvement plan with 8 different parameters. With the proposed plans, they concluded that the annual energy consumption in the villa type residence decreased by 13.79%, 19.27% , and 56.9%, respectively, according to the 1st, 2nd, and 3rd energy improvement levels, and 22.84%, 28.85 and 58.5% in the apartment type residence [25].

Lu et al. They examined more than a hundred articles published from 1999 to 2016 and the 12 most used BIM programs. In the research, the connection between BIM and green structures was investigated in depth. This study focuses on the effectiveness of BIM use in the design, construction, commissioning, and improvement processes of green buildings; The functions of BIM for the analysis of green buildings in terms of energy, emissions, and ventilation and finally the effectiveness of BIM use for green building assessment systems are discussed in 3 main sections [26].

Edwards et al. They examined the transformation of non-residential buildings into sustainable and energy-efficient structures with the help of BIM software and demonstrated the practicality of decision support tools for obtaining green building certifications such as BREEAM and LEED [27].

Özarısoy and Altan made suggestions with Revit and GBS software for the improvement and optimization of the energy performance of the existing housing stock on a sample building in the TRNC. In the research, strategies that can increase the energy efficiency of designers, contractors, suppliers, and researchers have been developed by using market data for sustainable building design [28].

Khaddaj and Srour investigated the relationship between BIM and sustainability concepts and the possibilities of using BIM to reduce energy consumption in existing building stocks and revealed the role of BIM and a BIM-based roadmap in renovation works to increase building energy performance [29].

Habibi et al. The results of the scenarios created by investigating the effect of the renovation of the building roofs on the building energy consumption have been revealed. The proposed roof alternative is an outside-in photovoltaic panel, EPDM membrane, and insulation layer. The main

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purpose of the study is to reveal the feasibility of converting an old building to both water resistance and energy generation [30].

Jalaei and Jrade BIM proposed an integrated method that connects energy analysis and cost estimation tools to the green building certification system. The designers proposed a system that automatically evaluates LCA, energy analysis, LEED, and cost estimations during the concept design phase of the building and demonstrated the feasibility of this proposal through a real building model [31].

Elnabawi and Hamza compared the energy consumption analyses of three different housing samples in three different locations (Cairo, Alexandria, Asyut) with Revit and Design Builder software, and as a result, the simulation obtained with Design Builder gave more accurate results than Revit. They concluded that their results were very close to the true values [32].

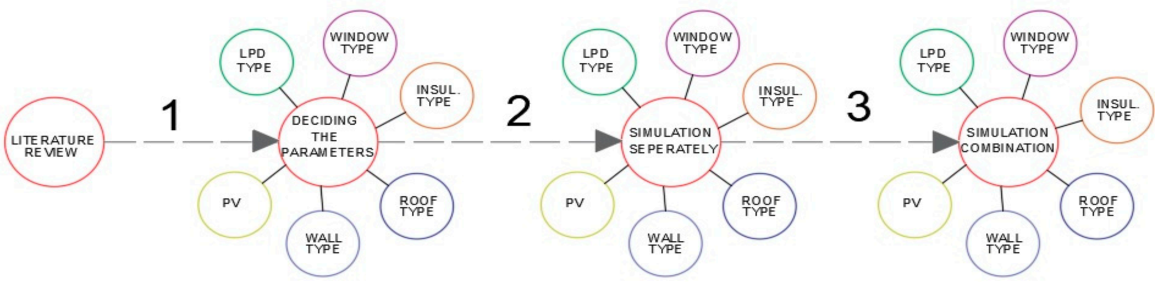
Chong and Wang examined the contributions of BIM to sustainable development by addressing the concepts of sustainability in the conceptual design of the project, concept design, application projects, and building construction processes. With the study, they established the relationship between 'BIM and green evaluation criteria' and 'BIM and renewable energy' to identify the deficiencies of the specifications, standards, and rules that are decisive in practice and to develop recommendations [33].

Egwunatum et al. They investigated the way and method of using BIM for solutions that reduce the energy needed in the use of buildings, reduce carbon emissions and increase the quality of building comfort. In this context, they conducted a literature review within the framework of energy consumption, energy performance, and energy evaluation of buildings. As a result of the review, it was concluded that the integrated use of energy analysis software with BIM guides designers in creating an optimized energy model. To confirm the conclusion reached, analyzes were made specifically for the Arboleda Project in the Dominican Republic and showed that it helped the world reach the first 103% positive energy building [34].

3. Material and Method

This research aims to produce the most suitable scenario that can strengthen the energy performance of existing building stocks with BIM and GBS software. For this purpose, a sample residential building has been selected where data can be easily obtained and access is possible to examine. Contrary to studies in which similar studies were conducted before, investigating the use of BIM in the renewal phase, not in the design phase, is the original value of our study. Increasing energy performance, reducing carbon emissions, and investigating the costs of these targets is not subject that finds a wide place in the literature.

While conducting the research, 192 different scenarios were developed by making combinations with 6 different parameters, and the initial investment costs of the renewal activities and the energy benefit and depreciation calculations were matched. With this overlay, its applicability to existing housing stocks is emphasized. Figure 1 shows the stages of the study and the flow chart.



Working flow chart.

Figure 1. Stages of the study and flow chart.

3.1. Current Housing Information

The building where the study was conducted is at 38.7180 latitude and 39.8665 longitude. As a location, it is located in Yazıbaşı in the Kovancılar district of Elazığ province in the east of Turkey. In the location of the building, winters are cold-hard and summers are hot-dry (Figure 2).

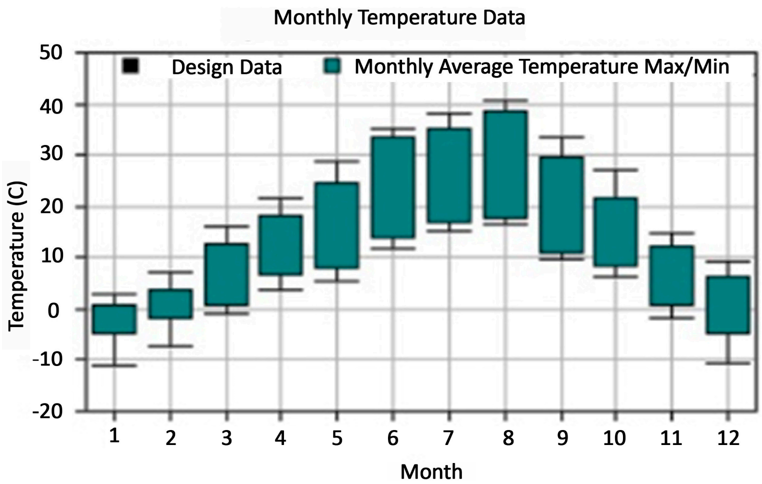


Figure 2. Kovancilar / Elazig monthly temperature data .

The building has a total of 3 floors and consists of a ground floor and two floors above it. The number of users of the building is 9 people. Each floor consists of independent residences and each floor contains 1 living room, 3 rooms, kitchen, toilet, and bathroom spaces. The roof is cold and is also used as a warehouse. The building usage area is 254 m2 (Figure 3).

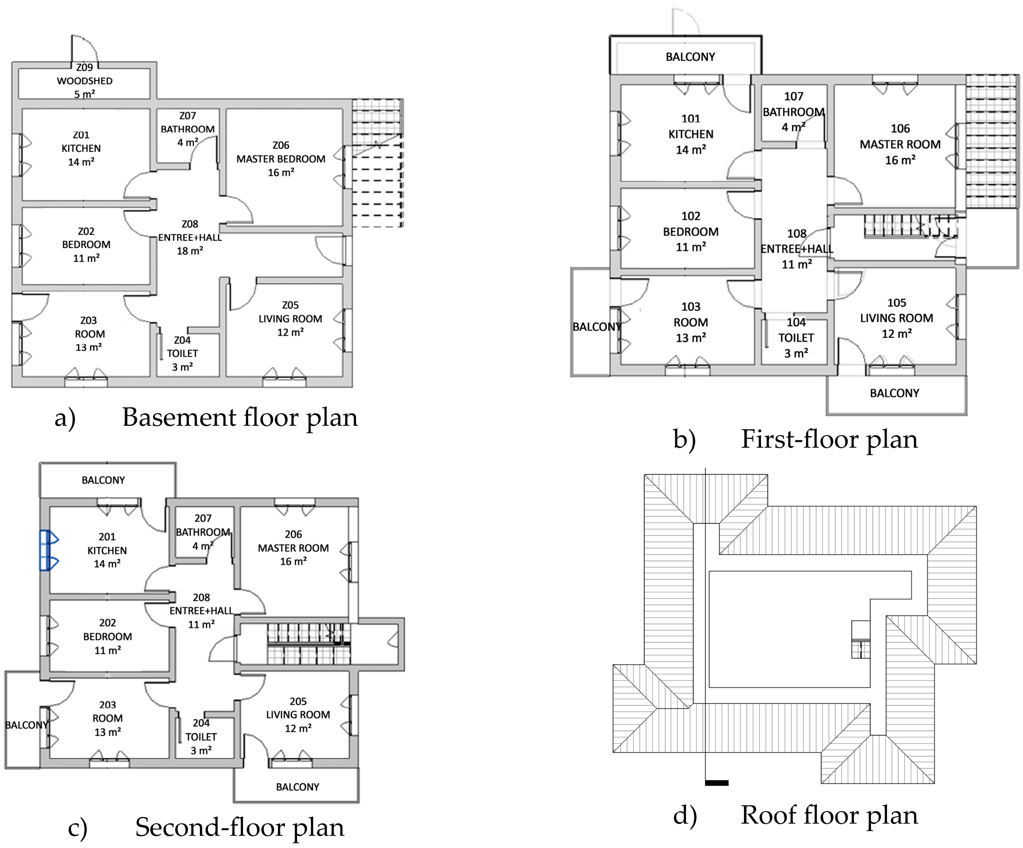


Figure 3. Residential Floor Plans a) ground floor plan, b) 1st floor plan, c) 2nd floor plan d) roof floor plan.

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Although the building is oriented in the north-south direction, its four facades are open. The transparency ratios on the facade of the building are 15% south, 11% north, 15% east, and 25% west. (Figure 4)

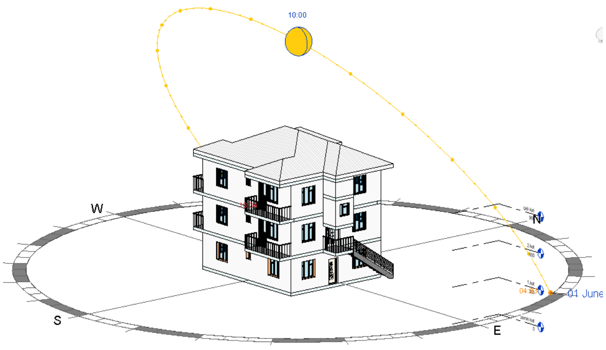
a) Entrance elevation

b) Left side elevation

Figure 4. Images of the existing house; a) entrance façade, b) left side elevation.

With the data taken from the field, the building was converted into a 3D model in the Autodesk Revit program. While creating the model, care was taken to use the existing materials of the building, the location, and the orientation of the building correctly, and to make it twin with reality (Figure 5).

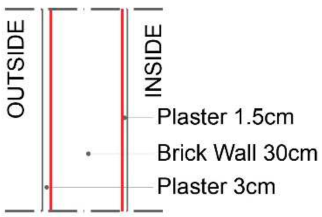
a)



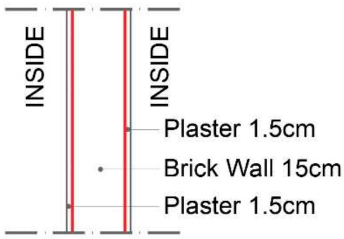
b)

Figure 5. a) 3D model, b) render image of the sample house.

The outer shell of the building is brick+plaster+paint (30cm+3cm) and there is no thermal insulation material. (Figure 6) Mezzanine floors consist of 5cm leveling concrete on 15cm reinforced concrete flooring and 2cm laminate flooring as floor covering. The building roof is metal roofing and the covering material has undergone deformation. Therefore, it leaks water in rainy weather. The windows are double-glazed except for the ground floor and the stair floor (Table 1).



a) External Wall



b) Internal Wall

Figure 6. Existing building exterior and interior wall section.

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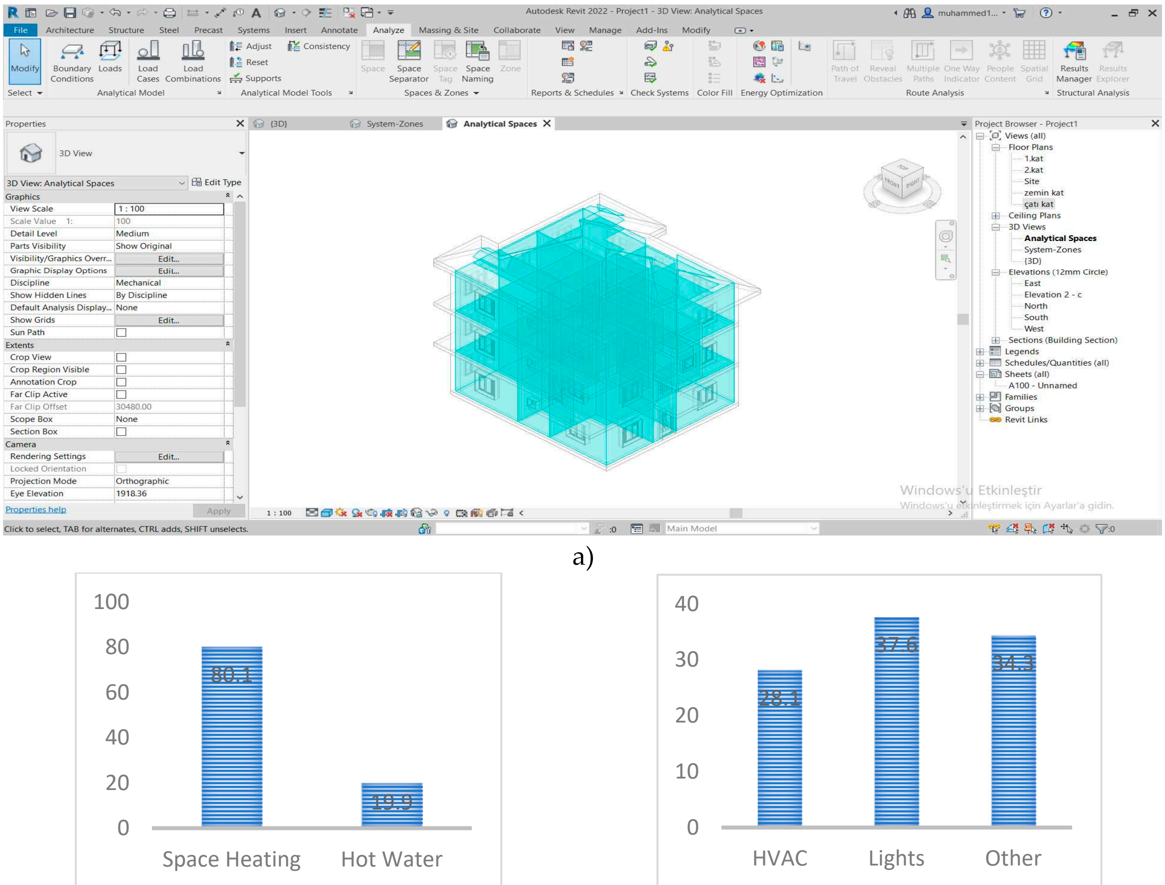
Table 1. Thermal permeability coefficients of building components.

Component	Material	Measurement	Unit	Thermal Permeability Coefficient (U)
Outer wall	Brick + Plaster + Paint	36	cm	1,58
Interior wall	Brick + Plaster + Paint	21	cm	2,33
Roof	Metal	0,5	cm	0,70
Floor	Reinforced concrete + leveling + Parquet	23	cm	2,48
Window	single glass / double glazing	4/4+12+4	cm	3,13 / 6,70 / 2,86

3.2. Analysing Results of Existing Residential Building Energy Analysis

To perform the energy performance analysis of the existing issue, an energy model was created in the Revit model, and then energy data entries were made. The created energy model was exported in gbxml format and imported into GBS software and made ready for analysis. (Figure 7. a) With the GBS analysis, it has been seen that the annual fuel consumption is 241,021.00 MJ and this consumption is 80.1%, 19.9% hot water for heating purposes (Figure 7.b.) The annual electricity consumption is calculated as 26,147.00 kWh and 37.6% of this expenditure is lighting, Calculated for 28.1% HVAC and 34.3% for other purposes (Figure 7. c). Again, from the calculations obtained, it was seen that the energy expenditure intensity was 1.321.00 MJ/m2/year, and the carbon emission was 12.00 mg.



a)

b)

c)

Figure 7. Existing Building Energy Performance Analysis a) Revit energy model b) Existing residential fuel use c) Existing residential electricity use.

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The analyzes obtained with GBS were calculated according to the unit costs of consumer prices in Turkey, and annual and lifetime costs were calculated. The fuel unit cost is 0.04 TL, electricity unit cost is 0.91 TL. While calculating the lifetime cost, the remaining life of the building is calculated as 30 years. A 6.1% discount was calculated from the calculated lifetime cost (Table 2).

Table 2. Expenditure costs.

Explanation	Unit	Amount	Unit price (TL)	Cost (Year) (TL)	Cost (Lifetime) (TL)
Fuel (Natural Gas)	MJ	241,021.00	0.04	9,640.84	271,582.46
Electric	kWh	26,147.00	0.91	23,793.77	670,270.00

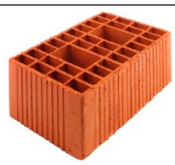
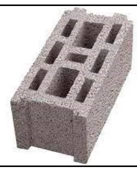
3.3. Changing Building Parameters

To develop alternative scenarios of the existing building, 6 parameters were determined and 192 different results were obtained as a result of the combinations of these parameters with each other. The selection of the determined parameters was obtained from the literature reviews and the results obtained from the previous studies.

3.3.1. Changing the Building Exterior Wall Material

The exterior walls of the building currently consist of 30 cm thick brick material. It is covered with 3 cm plaster and paint on the outside of the brick material, and 1.5 cm on the inside with gypsum plaster and paint material. The interior walls are made of 20 cm brick walls and 1.5 cm gypsum plaster and paint coatings are made on both sides of the wall. For the optimum wall material selection, the most commonly used pumice block and aerated concrete materials were chosen as alternatives, apart from the existing brick material. Alternative results were found with only material change without changing the section thickness with the coatings on the wall section (Table 3).

Table 3. U-values of the exterior and interior walls of the building according to the wall materials.

	Brick	Bimsblok	Aerated concrete
			
U (Outside Wall)	1,58	0,66	0,36
U (Inside Wall)	2,33	0,98	0,53

The most suitable section type was determined by performing performance analyses based on the existing wall section of the building and the new wall sections created with the newly proposed pumice block and aerated concrete materials (Table 4).

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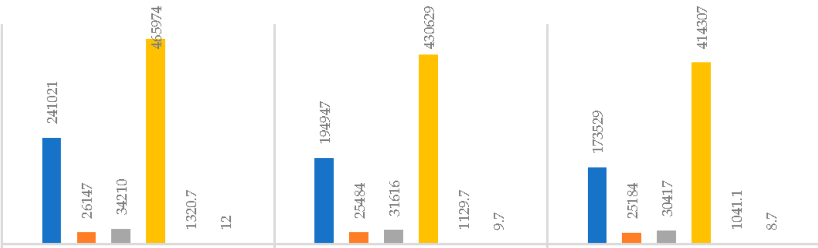
Table 4. Energy analysis results according to wall materials.

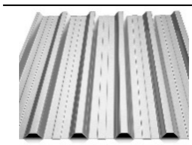
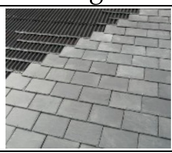
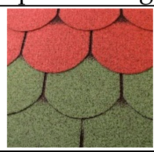


	Brick	Bimsblok	Aerated Concrete
Fuel Consumption (MJ) (Annual)	241021	194947	173529
Electricity Consumption (kWh) (Annual)	26147	25484	25184
Energy Cost (TL) (Annual)	34210	31616	30417
Energy Cost (TL) (Life Cycle)	465974	430629	414307
Energy Use Intensity (MJ/m2/year)	1320.7	1129.7	1041.1
Carbon Emission (Mg)	12	9.7	8.7

3.3.2. Results Obtained with Change in Roofing Material

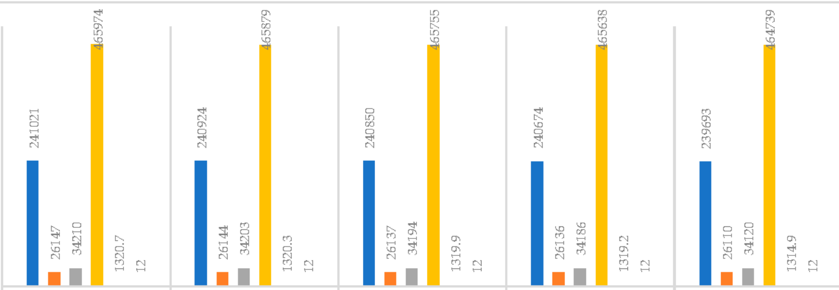
To examine the current state of the building roof and how the building energy performance and carbon emission values change with variable material parameters, 4 more alternative materials to the existing metal material were selected and analyzed. In the selection of alternative materials, commonly used materials were preferred (Table 5).

Table 5. Roof U values according to roofing materials.

	Metal	Roofing Slate	Roofing Tile	Asphalt Shingle	Wood Shake
					
U Value	0,70	0,69	0,67	0,65	0,54

Alternative results were obtained by performing building energy performance analysis on alternative roof types created with alternative 4 new materials together with the existing roof covering of the building, metal coating (Table 6).

Table 6. Building energy performance analysis according to roofing materials.

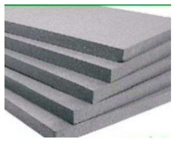


	Metal	Roofing Slate	Roofing Tile	Asphalt Shingle	Wood Shake
Fuel Consumption (MJ) (Annual)	241021	240924	240850	240674	239693
Electricity Consumption (kWh) (Annual)	26147	26144	26137	26136	26110
Energy Cost (TL) (Annual)	34210	34203	34194	34186	34120
Energy Cost (TL) (Life Cycle)	465974	465879	465755	465638	464739
Energy Use Intensity (MJ/m2/year)	1320.7	1320.3	1319.9	1319.2	1314.9
Carbon Emission (Mg)	12	12	12	12	12

3.3.3. Results Obtained with Change in Thermal Insulation Material

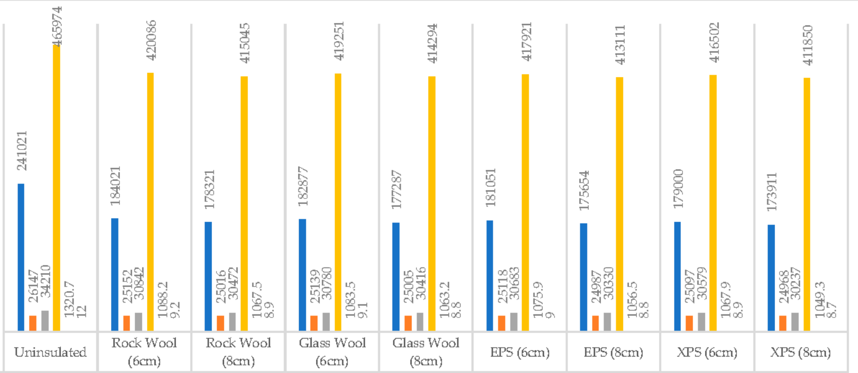
In the current state of the building, there is no thermal insulation layer. Building energy performance analysis by adding the most commonly used 4 different thermal insulation materials (Rockwool, glass wool, EPS, and XPS) and each thermal insulation material in two different section thicknesses (6cm and 8cm), which are the most widely used in terms of thermal insulation of the building. has been made (Table 7).

Table 7. Wall U values according to thermal insulation materials.

	Rock wool	Glass wool	EPS	XPS
				
U Value (6cm)	0,43	0,41	0,38	0,35
U-Value (8cm)	0,34	0,33	0,30	0,28

The results obtained with the building energy performance analysis made by adding 4 different materials with 2 different section thicknesses to the building exterior walls are as in Table 8.

Table 8. Energy analysis results according to thermal insulation materials.



	Uninsulated	Rock Wool (6cm)	Rock Wool (8cm)	Glass Wool (6cm)	Glass Wool (8cm)	EPS (6cm)	EPS (8cm)	XPS (6cm)	XPS (8cm)
Fuel Consumption (MJ) (Annual)	241021	184021	178321	182877	177287	181051	175654	179000	173911
Electricity Consumption (kWh) (Annual)	26147	25152	25016	25139	25005	25118	24987	25097	24968
Energy Cost (TL) (Annual)	34210	30842	30472	30780	30416	30683	30330	30579	30237
Energy Cost (TL) (Life Cycle)	465974	420086	415045	419251	414294	417921	413111	416502	411850
Energy Use Intensity (MJ/m2/Year)	1320.7	1088.2	1067.5	1083.5	1063.2	1075.9	1056.5	1067.9	1049.3
Carbon Emission (Mg)	12	9.2	8.9	9.1	8.8	9	8.8	8.9	8.7

3.3.4. Results Obtained with Change in Window Glass Material

The building's existing glass material (P1) is 4mm single glass. The glasses of the building windows are simulated by replacing them with alternative glass materials such as low E double glazing (P2), uncoated double glazing (P3), and triple glazing (P4) (Table 9).

Table 9. Window U and HCG values according to Glass Materials.

	Available Glass	Low-E Double Glazing	Uncoated Double Glazing	Triple Glazing
U Value	3.13/6.70/2,86	2.10	1.99	1.53
SHGC	0.21/0.19/0.76	0.24	0.62	0.68

The situation and changes that occur when the existing P1 type window of the building is proposed with P2, P3, and P4 materials are shown in the chart in Table

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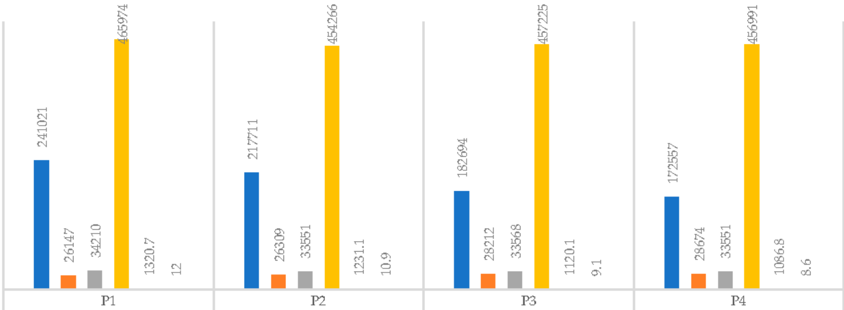
Table 10. Energy analysis results by glass materials.

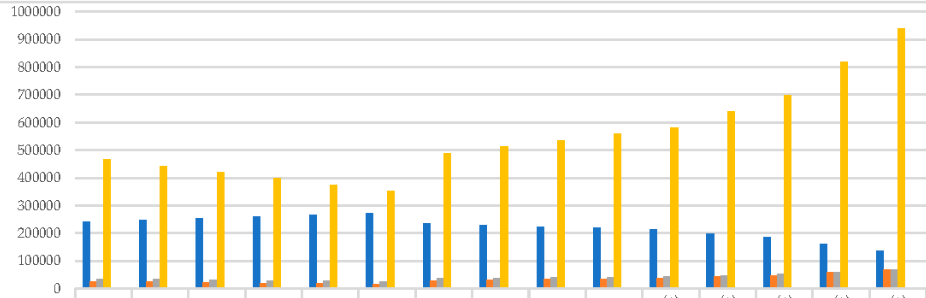


	P1	P2	P3	P4
Fuel Consumption (MJ) (Annual)	241021	217711	182694	172557
Electricity Consumption (kWh) (Annual)	26147	26309	28212	28674
Energy Cost (TL) (Annual)	34210	33551	33568	33551
Energy Cost (TL) (Life Cycle)	465974	454266	457225	456991
Energy Use Intensity (MJ/m2/Year)	1320.7	1231.1	1120.1	1086.8
Carbon Emission (Mg)	12	10.9	9.1	8.6

3.3.5. Results Obtained with Change in Lighting

Luminous power intensity (maximum luminous power per unit area) is abbreviated as LPD. To examine the effect of LPD on building energy performance, the LPD value of the existing building (10.76W/m²) was reduced by 20, 40, 60, 80, 100, and 20, 40, 60, 80, 100, 150, 200, 300, 400 by increasing the results were presented by analyzing 14 different scenarios Table 11.

Table 11. Energy analysis results according to the LPD value of the lighting system.

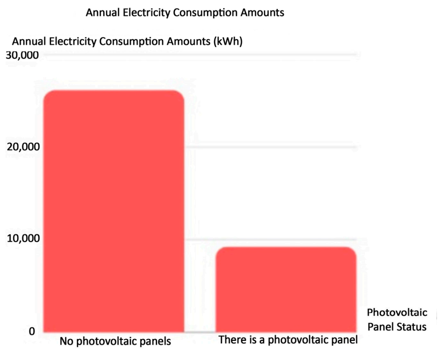


	Current Situation	(-) %20 8.61W/m2	(-) %40 6.46W/m2	(-) %60 4.31W/m2	(-) %80 2.15W/m2	(-) %100 0.00W/m2	(+) %20 12.92W/m2	(+) %40 15.07W/m2	(+) %60 17.22W/m2	(+) %80 19.38W/m2	(+) %100 21.53W/m2	(+) %150 26.91W/m2	(+) %200 32.29W/m2	(+) %300 43.06W/m2	(+) %400 53.82W/m2
Fuel Consumption (MJ) (Annual)	241021	246960	252968	259042	265150	271300	235123	229301	223569	217882	212238	198273	184768	159498	136434
Electricity Consumption (kWh) (Annual)	26147	24021	21897	19737	17622	15452	28279	30413	32551	34692	36838	42217	47613	58457	69428
Energy Cost (TL) (Annual)	34210	32532	30860	29156	27495	25787	35896	37586	39284	40987	42695	46987	51313	60089	69076
Energy Cost (TL) (Life cycle)	465974	443121	420341	397138	374521	351255	488928	511952	535077	558266	581533	639987	698910	818437	940832
Energy Use Intensity (MJ/m2/Year)	1320.7	1313.9	1307.5	1300.8	1294.8	1288.3	1327.7	1335	1342.8	1350.7	1358.9	1380.2	1403.5	1457.8	1522.6
Carbon Emission (Mg)	12.00	12.30	12.60	12.90	13.20	13.50	11.70	1.40	11.10	10.90	10.60	9.90	9.20	8.00	6.80

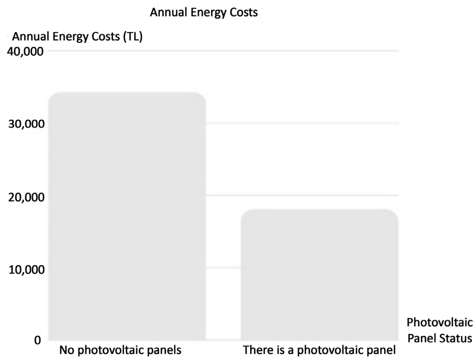
3.3.6. Results Obtained with Photovoltaic Panel Application

It has been investigated how the building energy consumption changes when a photovoltaic panel (PV) is added to the roof of the building. The roof area of the building is 153 m2. The area where the panel can be installed is 88 m2. A monocrystalline solar panel with an efficiency of 13.8% was chosen for the simulation. The cost of 1 m2 of the panel is 1104.62 TL/1Watt=8 TL. Since the panel area to be built is 88 m², the total cost of the panel is 97,136,89 TL. The graphs of the building energy performance analysis results of the PV panels are shown in Table 12.

Table 12. Annual electricity and energy consumption by PV panel status a) electricity b) energy.



a



b

3.3.7. Results Obtained by Evaluation of All Alternative Scenarios

Finally, 192 alternative scenarios were made in combination with the wall (2 types), roof (4 types), insulation (8 types), and windows (3 types) alternatives. In the above studies, each parameter was separately simulated and evaluated. At this stage, the most efficient option by combining all the parameters, and the possibility of combining different parameters was also taken into consideration. In addition, another purpose of simulating all parameters together is to prove the accuracy and reliability of the study. Wall, roof covering, and window glass materials and thermal insulation status of the existing house are not included in these scenarios. Lighting (LPD) and photovoltaic panel (PV) are excluded from this combination. The best results of the combination of Wall, Roof, Insulation, and Window are combined with the best results of LPD and PV simulations. (Figure 8).

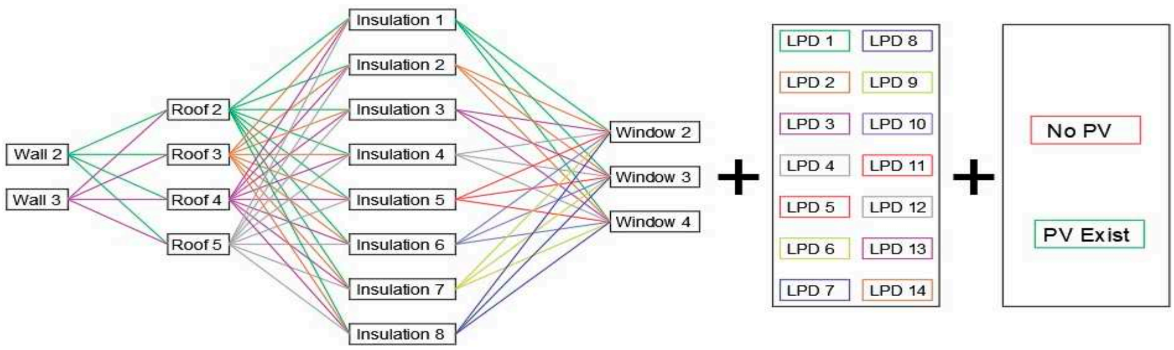


Figure 8. Parameters and combination simulations.

4. Findings and Discussions

According to the simulation results for the wall materials, it has been shown that the changes in the wall material do not have a serious effect on the building's electricity consumption, but cause great changes in the fuel consumption. Among the options, the gas concrete wall section showed higher performance compared to the pumice block and brick. (Table 13)

Table 13. Wall materials available and alternative scenario analysis results.

wall material	Annual fuel consumption (MJ)	Annual electricity consumption (kWh)	Annual energy cost (TL)	Life cycle energy cost (TL)	Energy usage intensity (MJ/m2/year)	CO2 emissions (Mg)
Brick	241021	26147	34210	465974	1320.7	12.0
Bimsblok	194947	25484	31616	430629	1129.7	9.7
Aerated concrete	**173529**	**25184**	**30417**	**414307**	**1041.1**	**8.7**

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In the simulation tests for roofing materials, it is striking that there is no significant change in the performance of alternative materials on the roof. Wood and stone sheet roofing materials were the highest and lowest-performing options, respectively. Shingle was in the 2nd place and the tile was in the 3rd place. However, the values are very close to each other. (Table 14)

Table 14. Roof materials available and alternative scenario analysis results.

Roofing material	Annual fuel consumption (MJ)	Annual electricity consumption (kWh)	Annual energy cost (TL)	Life cycle energy cost (TL)	Energy usage intensity (MJ/m2/year)	CO2 emissions (Mg)
Metal	241021	26147	34210	465974	1320.7	**12.0**
Stone Slab	240924	26144	34203	465879	1320.3	**12.0**
Tile	240850	26137	34194	465755	1319.9	**12.0**
Shingle	240674	26136	34186	465638	1319.2	**12.0**
Wood	**239693**	**26110**	**34120**	**464739**	**1314.9**	**12.0**

According to the results of the simulation tests performed by changing the thermal insulation materials, applying thermal insulation to the exterior walls of the building significantly reduces the building's fuel consumption. There is no significant reduction in electricity usage. Carbon emission rates are lowest in 8cm XPS material. Significant reduction in fuel consumption; It greatly reduces the lifetime energy cost of the building. The thermal insulation materials that increase the energy performance of the building the most are XPS, EPS, glass wool, and rock wool, respectively. Rock wool and glass wool materials also showed very close values for all parameters (Table 15).

Table 15. Heat insulation materials available and alternative scenario analysis results.

heat insulation material	Heat insulation material thickness	Annual fuel consumption (MJ)	Annual electricity consumption (kWh)	Annual energy cost (TL)	Life cycle energy cost (TL)	Energy usage intensity (MJ/m2/year)	CO2 emissions (Mg)
non-insulated	X	241021	26147	34210	465974	1320.7	12.0
Rock wool	6 cm	184021	25152	30842	420086	1088.2	9.2
	8 cm	178321	25016	30472	415045	1067.5	8.9
Glass wool	6 cm	182877	25139	30780	419251	1083.5	9.1
	8 cm	177287	25005	30416	414294	1063.2	8.8
EPS	6 cm	181051	25118	30683	417921	1075.9	9.0
	8 cm	175654	24987	30330	413111	1056.5	8.8
XPS	6 cm	179000	25097	30579	416502	1067.9	8.9
	8 cm	**173911**	**24968**	**30237**	**411850**	**1049.3**	**8.7**

Window glass type according to building energy performance results for P1, P2, P3, and P4 glass materials; significantly affects the fuel consumption, energy use intensity, and carbon emission of the building. There is no significant change in electricity usage and costs. The glass materials that increased the building energy performance the most were P4, P3, P2, and P1, respectively. Carbon emissions are the lowest in P4. (Table 16)

Table 16. Existing glass materials and alternative scenario analysis results.

Roofing material	Annual fuel consumption (MJ)	Annual electricity consumption (kWh)	Annual energy cost (TL)	Life cycle energy cost (TL)	Energy usage intensity (MJ/m2/year)	CO2 emissions (Mg)
P1	241021	26147	34210	465974	1320.7	12.0
P2	217711	26309	33551	454266	1231.1	10.9
P3	182694	28212	33568	457225	1120.1	9.1
P4	**172557**	**28674**	**33551**	**456991**	**1086.8**	**8.6**

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When the LPD value is reduced, electricity consumption, cost, and energy usage intensity have decreased. Fuel consumption and carbon emissions are increasing. When the LPD value is increased, electricity consumption has increased, but fuel consumption and carbon emissions have decreased. While the LPD value decreased, fuel consumption increased slightly, while the LPD value increased, costs, energy use intensity, and electricity consumption increased significantly. The alternative (0 W/m²) with an LPD value of 100% less than the current value showed the best performance. Although it caused an increase of 30,279 MJ in annual fuel consumption, the savings of 10,695 kWh in electricity use allowed great reductions in costs and energy use intensity. During its 30-year life cycle, 114,719.00 TL was saved. (Table 17)

Table 17. Results of LPD values available and alternative scenario analysis.

LPD	Annual fuel consumption (MJ)	Annual electricity consumption (kWh)	Annual energy cost (TL) (TL)	Life cycle energy cost (TL)	Energy usage intensity (MJ/m2/year)	CO2 emissions (Mg)
Current Situation	241021	26147	34210	465974	1320.7	12.0
(-) %20--8.61 W/m²	246960	24021	32532	443121	1313.9	12.3
(-) %40---6.46 W/m²	252968	21897	30860	420341	1307.5	12.6
(-) %60---4.31 W/m²	259042	19737	29156	397138	1300.8	12.9
(-) %80---2.15 W/m²	265150	17622	27495	374521	1294.8	13.2
(-) %100---0 W/m²	**271300**	**15452**	**25787**	**351255**	**1288.3**	**13.5**
(+) %20---12.92 W/m²	235123	28279	35896	488928	1327.7	11.7
(+) %40---15.07 W/m²	229301	30413	37586	511952	1335.0	11.4
(+) %60---17.22 W/m²	223569	32551	39284	535077	1342.8	11.1
(+) %80---19.38 W/m²	217882	34692	40987	558266	1350.7	10.9
(+) %100---21.53 W/m²	212238	36838	42695	581533	1358.9	10.6
(+) %150---26.91 W/m²	198273	42217	46987	639987	1380.2	9.9
(+9 %200---32.29 W/m²	184768	47613	51313	698910	1403.5	9.2
(+) %300---43.06 W/m²	159498	58457	60089	818437	1457.8	8.0
(+) %400---53.82 W/m²	136434	69428	69076	940832	1522.6	6.8

Photovoltaic panel selection and the costs of these choices are explained in the sections above. It has been calculated that the system will generate 16,936 kWh of electricity annually with the monocrystalline solar panel PV panels with 13.8% efficiency installed on an area of 88 m² of the building roof surface. The cost of panel installation is 97,136,89 TL. Considering the current annual electricity consumption of the building, the depreciation period is calculated as 6 years.

According to the simulations made for all alternative scenarios, the best alternative is the alternative from the components D2, C4, I8, and P4. In this scenario, the fuel consumption is 92.287.00 MJ and the energy usage intensity is 767.3 MJ/m2/year. In electricity consumption, the D2, C4, I8, and P2 scenarios give the best results. The annual electricity consumption is 24,912.00 kWh, the annual energy consumption is 28,229.00 TL and the lifetime consumption value is 384,500.00 TL.

4.1. Comparison of Optimum Alternative Scenario and Current Situation

In this part of the study, the energy performance results of the existing building were compared with the optimum alternative scenario where the best options selected for all parameters analyzed were applied together. Energy analysis results of the existing house, all parameters, and alternative scenarios are given (Table 18).

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Table 18. Energy analysis results of the existing building, all parameters, and the alternative scenario created.

Parameter	Annual fuel consumption (MJ)	Annual electricity consumption (kWh)	Annual energy cost (TL)	Life cycle energy cost (TL)	Energy usage intensity (MJ/m2/year)	CO2 emissions (Mg)
Current residence	241021	26147	34210	465974	1320.7	12.0
Optimal alternative scenario	**92287**	**11016**	**13715**	**186798**	**519.4**	**4.6**

With the alternative scenario created, the energy performance of the existing house has been significantly increased. 61% savings in annual fuel consumption and 64% in electricity consumption were achieved. While the fuel consumption is 241,021.00 MJ for the existing residence, it is 92,287.00 MJ for the alternative scenario. Electricity usage is 26,147,00 kWh and 11,016,00 kWh for the existing residence and alternative scenario, respectively. Annual and lifetime energy costs were saved by 59%. The lifetime energy cost of the building has been reduced by TL 279,176.00. Similar serious reductions were observed for energy use intensity and CO2 emissions. Triple glass, aerated concrete wall, and 8 cm XPS thermal insulation applications, respectively, are the options that reduce the fuel consumption of the building the most. The triple glazing application in the windows reduced the building fuel consumption from 241,021.00 MJ to 172,557.00 MJ. On the other hand, parameters other than photovoltaic panels and lighting systems did not affect electricity consumption. With the installation of photovoltaic panels on the roof of the building, an annual saving of 16,936.00 kWh was achieved in electricity consumption. With the reduction of the LPD value of the lighting fixtures by 100%, a reduction of 10,695.00 kWh was achieved in annual electricity consumption.

The lowest annual and lifetime energy costs are provided by the photovoltaic panel and lighting system parameters that reduce electricity consumption the most. The most important reason for this result is that the unit price of electricity is much higher than that of fuel. Finally, the low energy costs provided for the photovoltaic panel will make the user feel its effect in the long run due to the high initial investment costs of the application.

4.2. Financial Value of Improvement and Amortization Periods

In this study, the return on investments was calculated considering the effects of the selected renovation works on the energy performance and costs of the sample building, as well as the initial investment costs and the savings in the building. Thus, the relevant institutions, organizations, and individuals were informed about the economic feasibility of building reinforcement works. For the costs of reinforcement techniques, the current unit price list of the Ministry of Environment and Urbanization and the online resources of the manufacturers were used (Table 19).

Table 19. Quantity, material + labor price, and total cost of selected renovation works.

Strengthening method		Unit	Amount	Material + labor price	Total cost
Wall	wall demolition	m²	558	20 TL	11.160,00 TL
	masonry	m²	558	80 TL	44.640,00 TL
	Gypsum plaster + paint	m²	690	26 TL	17.940,00 TL
	Rough plaster + paint	m²	320	82 TL	26.240,00 TL
	Total (Wall)				**99.980,00 TL**
Roof	roof removal	m²	153	32 TL	4.900,00 TL
	roof installation	m²	153	150 TL	22.950,00 TL
	Total (Roof)				**27.850,00 TL**

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Window	window removal	m^2	55	14.5 TL	800,00 TL
	window suit	m^2	55	310 TL	17.050,00 TL
		Total (Window)			**17.850,00 TL**
Thermal insulation		m^2	320	92 TL	**29.440,00 TL**
Lighting		piece	56	50 TL	**2.800,00 TL**
photovoltaic panel		m^2	88	1104 TL	**97.130,00 TL**
Total of All Manufacturing (excluding taxes)					**275.050,00 TL**

The monetary compensation for the proposed improvement works for the existing building is 275,050,00 TL. The annual energy cost of the existing building is 34,210,00 TL. The annual energy cost of the alternative scenario created is 11.016 TL. Therefore, an annual saving of 23,194.00 TL was achieved. As a result, the payback period has been calculated as approximately 12 years, considering the investment cost of retrofitting and the annual savings it provides.

5. Conclusion

The construction industry is one of the largest stakeholders in global energy consumption and offers great potential to reduce the use of fossil fuels and to get rid of the negative effects of global warming. Since existing buildings constitute a very large part of the building stock, it is of great importance to increase the energy performance of existing buildings to minimize greenhouse gas emissions in the construction industry.

BIM technology is a set of technologies, processes, and policies that allow buildings to be collaboratively designed, constructed, and operated in a virtual space. BIM provides the opportunity to analyze the energy performance of existing buildings and simulate and analyze retrofit options through the data-rich, object-oriented, intelligent, and parametric 3D model that can be created in-house, thus creating the best retrofit scenario for existing buildings.

In this study, a sample residential application study was conducted to investigate the effectiveness of BIM in the renovation of existing buildings and to develop suggestions about applicable and optimized retrofitting techniques. The energy performance of the existing house, which was modeled in Revit software and processed with the necessary data, was calculated in the GBS simulation tool. Simulation results; energy consumption (annual / lifetime) (fuel and electricity), cost (annual / lifetime), energy use intensity, and amount of CO2 emissions. To improve the energy performance of the existing building, retrofitting methods have been developed based on 8 parameters determined by using the literature and simulation results: building orientation, building envelope (wall, roof, thermal insulation, window, and facade transparency ratio), lighting and photovoltaic panel. Within the scope of each parameter, different options were developed and energy analyzes were made. Then, to ensure the accuracy and reliability of the data obtained, the effect of 192 alternative scenarios, which emerged as a result of different combinations of a total of 17 scenarios developed for 4 parameters, on the energy performance of the building was tested and comparisons were made. Finally, a comparison was made between the alternative building, which was created by using the most appropriate scenario determined for each parameter, and the existing building. In addition, the initial investment costs of the retrofitting works and the savings in the building were taken into account, and the return on investments was calculated.

The results obtained from the study are as follows:

The energy performance of the sample house has increased significantly with the applied retrofit techniques.

The building's annual fuel consumption was 61%, and electricity consumption was 64%. While the annual fuel consumption of the existing residence is 241,021.00 MJ, it is 92,287.00 MJ for the alternative building. Electricity usage is 26,147.00 kWh and 11,016.00 kWh for the existing residence and alternative scenario, respectively.In annual and lifetime energy cost savings were achieved by 59%. While the annual energy cost of the existing building is 34,210.00 TL, the annual energy cost of the alternative scenario created is 11,016.00 TL. The life cycle cost of the building has decreased from 465,974.00 TL to 186,798.00 TL. The annual CO2 emissions of the building have decreased from 12

Mg to 4.6 Mg. There was a decrease of 801.3 MJ/m2/year in the energy usage intensity of the building. The applications that increase the energy performance of the building the most are triple glazing, aerated concrete wall, and 8 cm XPS thermal insulation. The annual fuel consumption of the building has decreased by 68,464.00 MJ as a result of replacing the existing windows with triple glazing.

Except for the photovoltaic panel installation and the replacement of the lighting system, the renovation works did not affect the building's electricity consumption. With the installation of photovoltaic panels on the roof of the building, an annual saving of 16,936.00 kWh was achieved in electricity consumption. The total cost of the strengthening methods is 275,050.00 TL and the return on investment for retrofitting is approximately 12 years. The reinforcement work with the highest initial investment cost is the replacement of brick wall material with gas concrete, with a price of 99,980.00 TL. Despite the high initial cost of this application, the fact that it saves only 3,793.00 TL per year is an indication that it is not an ideal reinforcement method. The second application with the highest initial investment cost was the installation of photovoltaic panels on the roof of the building for 97,130.00 TL. However, 64% savings in annual electricity consumption provided by this application is an indication that it is a correct retrofit method. Triple glazing and 8 cm XPS thermal insulation applications, on the other hand, significantly reduced building fuel consumption, despite their relatively low investment costs. Thus, these applications have proven to be both economically and environmentally sound reinforcement options. Replacing the metal roofing material of the existing building with wood attracted attention with its high cost compared to the savings it provided and it turned out that it is not an ideal renewal method.

In this study, the use and efficiency of BIM technologies in retrofitting existing buildings were tested. It has been determined that BIM-based programs and auxiliary simulation tools are efficient tools for making energy analyzes of existing buildings, simulating retrofit scenarios, and comparing alternative designs.

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