A Cost Efficient Method Analysis of Energy Efficient Improvement of Historic Buildings

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ABSTRACT
Although the materials used in historical buildings are ecological, they can lag behind today's building systems in terms of building performance values. This situation causes much more energy consumption in historical buildings. Not being able to reach the desired comfort level with excessive energy consumption causes negative effects in terms of ensuring the sustainability of these structures. Many studies are carried out in order to ensure energy efficiency, which is one of today's problems in historical buildings. However, the determination of low-cost energy efficient solutions with small interventions is important in terms of choosing the most appropriate methods. In this context, within the scope of the study, energy efficient applications from small interventions to larger interventions were selected in three historical buildings with different construction systems in different regions. The energy consumption data of these applications were obtained with the Design Builder program, and the energy and intervention application costs were calculated. The payback periods of the applications were determined with the calculated costs. Effective applications with reimbursement as soon as possible have been identified. As a result, applications that pay for themselves in a short time are presented as suggestions.
Keywords: Energy Efficiency, Historical Buildings, Renovation, Restoration, Cost Analysis, Design Builder

INTRODUCTION
With the increase in the comfort demands of people in the world and the developing technology, the energy consumption and the emission of harmful gases have increased, which has led to the emergence of climate changes. This situation causes the formation of natural disasters that seriously affect the world. Structures are responsible for 31% of global energy demand and about one third of greenhouse gas emissions in the world (Shukla and Sharma, 2018). These data reveal the potential of energy saving in buildings. In this context, many studies are carried out within the framework of energy efficiency in buildings. Among the studies carried out, there are historical buildings that make up the cultural heritage (Egusquiza and Izkara, 2016; Becchio and etc, 2017;Bichlmair Becchio and etc, 2015; Pisello and etc, 2014; Ferrari and etc, 2016; Gagliano and etc, 2014; Ganobjak, 2014; Johansson and etc, 2014; Manzan and etc, 2015). Energy efficiency studies in historical buildings are important not only in terms of energy saving, but also in terms of transferring these cultural heritage structures to future generations. Historical buildings contain systems that are older and have poorer performance compared to today's systems. These systems cause historical buildings to fall behind today's standards and prevent the buildings from being sustainable. For this reason, there is a need to develop methods and practices that will help control environmental effects by increasing energy efficiency by preserving the original features of traditional buildings, which include heritage values, and by considering user comfort (Zagorskas and etc,, 2013). In this context,

today's cultural heritage is not only seen as a petrified memory of the past, but is also perceived as an active resource for future generations and intervened according to the conditions of the day. However, in order for the interventions to be effective, it is necessary to work on the balance of conservation and energy efficiency. Current practices should be carried out without compromising the heritage values of historical buildings, which are the potential riches of the past (Egusquiza and Izkara, 2016; Franco and Magrini, 2017). These studies have shown that energy efficient sustainability of historical buildings can be achieved with up-to-date modern methods and with the least impact. Among these applications, many studies have been carried out within the framework of internal insulation of walls, insulation of floors, improvement of the performance of windows, HVAC system solutions and renewable system integration. The cost of these applications, as well as the importance of what and how they are, and how long they will pay for themselves are important in terms of method selection. In this context, there are many exemplary studies within the scope of energy cost analysis (Ascione and etc, 2015; Ciulla and etc, 2016; Cho and etc, 2020; Güleroğlu and etc, 2020; Arumägi and Kalamees, 2014; Tiberi and Carbonara, 2016) but more studies are needed due to changing conditions. In this study, it is aimed to determine how long the physical applications carried out in the energy efficient improvement of historical buildings will pay for itself with the energy saving cost realized in the building. In this framework, three civil architectural structures from different climatic regions were selected and energy data were obtained with the simulation program. Then, cost analyzes were carried out with the current prices of official institutions. As a result, the most suitable solution methods that pay for themselves in the shortest time in the cost, energy, protection equation have been put forward.

MATERIAL AND METHOD

In this study, which aims to reveal how long the physical applications in the energy efficient improvement of historical buildings pay for themselves with the energy saving cost realized in the building, first of all, three civil architectural structures from different climatic regions were selected. Then, the technical data including physical, thermophysical and heating systems of these selected historical buildings were determined. The energy models of the buildings were created with these data. In the models created, applications that will provide energy savings are determined from small physical interventions to large physical interventions and five scenarios are foreseen for each structure. After this process, the energy saving and physical intervention prices of the scenarios were revealed. In determining the energy saving prices, the energy saving was found by subtracting the current situation and the energy consumption data in each scenario from the current scenario. Energy saving costs are determined by multiplying the determined energy values with the kWh gas unit prices in the region where the buildings are located (Başkent Natural Gas Distribution, Torosgaz Isparta Burdur Natural Gas Distribution, Enerya Kapadokya Gas Distribution)(Url-1, Url-2, Url-3). After determining the energy saving costs, the costs of the implementations were calculated based on the item numbers containing the unit implementation costs of the relevant ministries.

The Design Builder program, which uses the Energy Plus infrastructure, was used to calculate the energy efficiency of the scenarios. With the Design Builder program, visual geometric modeling of buildings can be made in 3D, the amount of heat gained and lost can be analyzed based on hourly data, and as a result of these analyzes, energy consumption values of the buildings can be found in total or per square meter. For this reason, the models created within the framework of the scenarios were evaluated with the Design Builder simulation program, and the energy consumption data in natural gas in kWh were determined. By dividing the energy and physical intervention costs with the graphics and tables prepared in the light of these data, it is calculated in how many years the applications will pay for themselves with the energy cost savings.

CASE STUDY

In this study, historical and traditional buildings with different construction systems in different climatic regions in Turkey were selected. The data of these structures are explained below.

General Features of Historic Buildings

In order to determine the energy/cost ratio in different climatic regions, the first of the three buildings selected is Ankara Province Güdül District (400 12´ North, 320 14´ East) 200 lot 3 parcels, the second one in Burdur Province (370 43´ North, 300 17´ East) 414 blocks 3 and the third is located in Niğde Province (370 59´ North, 340 42´ East) on block 269 and parcel 15 (Figure 1).

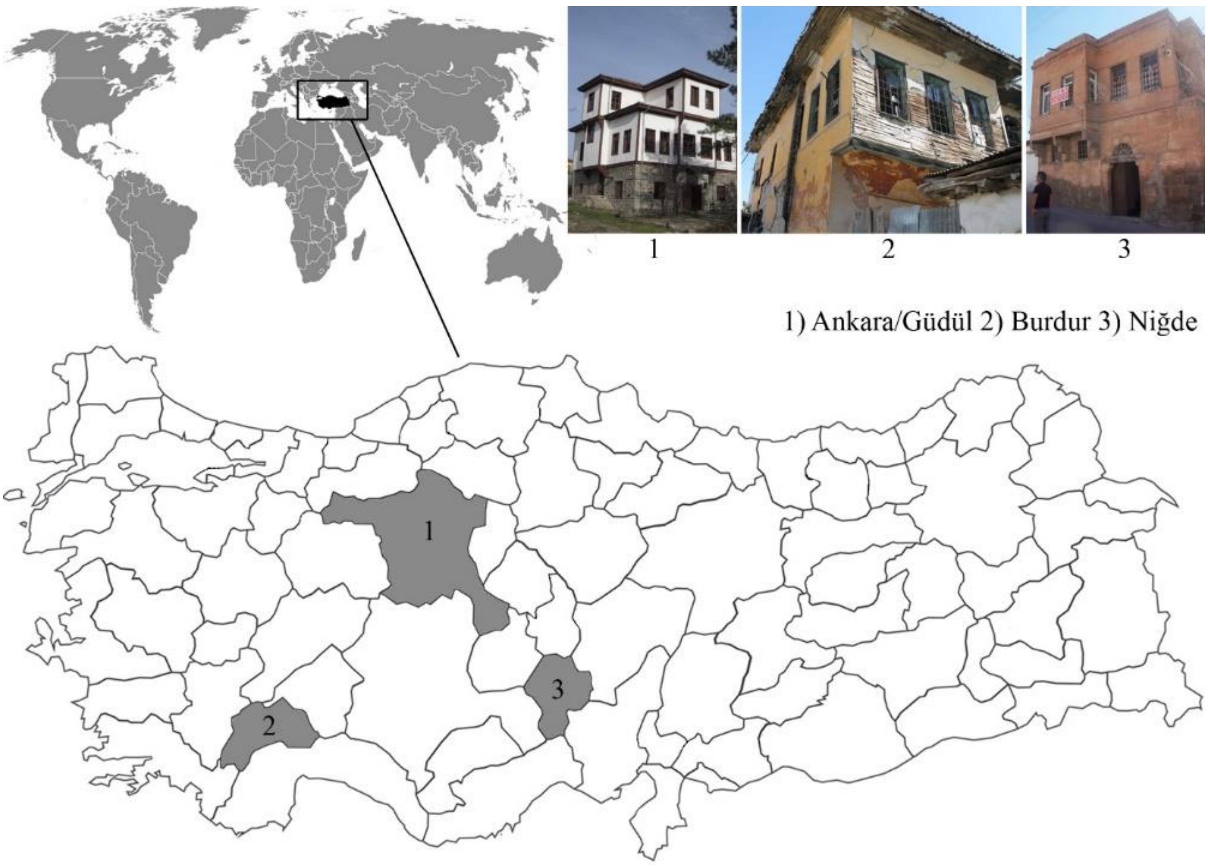


Figure 1. Locations of structures

The building in Ankara is approximately 290 m² and the ground floor was built by masonry and the first and second floors were built with brick infill between the wooden frame. Although rubble stone material is used on the outer walls of the ground floor, its thickness is designed to be 68 cm on average. The thickness of the upper floor walls is 20 cm in total. The construction area of the building located in Burdur Province is 357 m². The ground floor walls of the two-storey building were built of adobe material with a thickness of 85 cm as masonry, and the walls of the upper floor were built in the form of a bagdadi system with a thickness of 20 cm. The northeast and southeast facade walls of the upper floor are made of masonry mud bricks as in the ground floor. The building in Niğde is 175 m² and has two floors. Although both floors were built in the masonry technique, stone material was used. The ground snow wall thickness is 70 cm on average, the upper floor wall thickness is 60 cm in the north, 80 cm in the south, and 20 cm in the east and west (Figure 2).

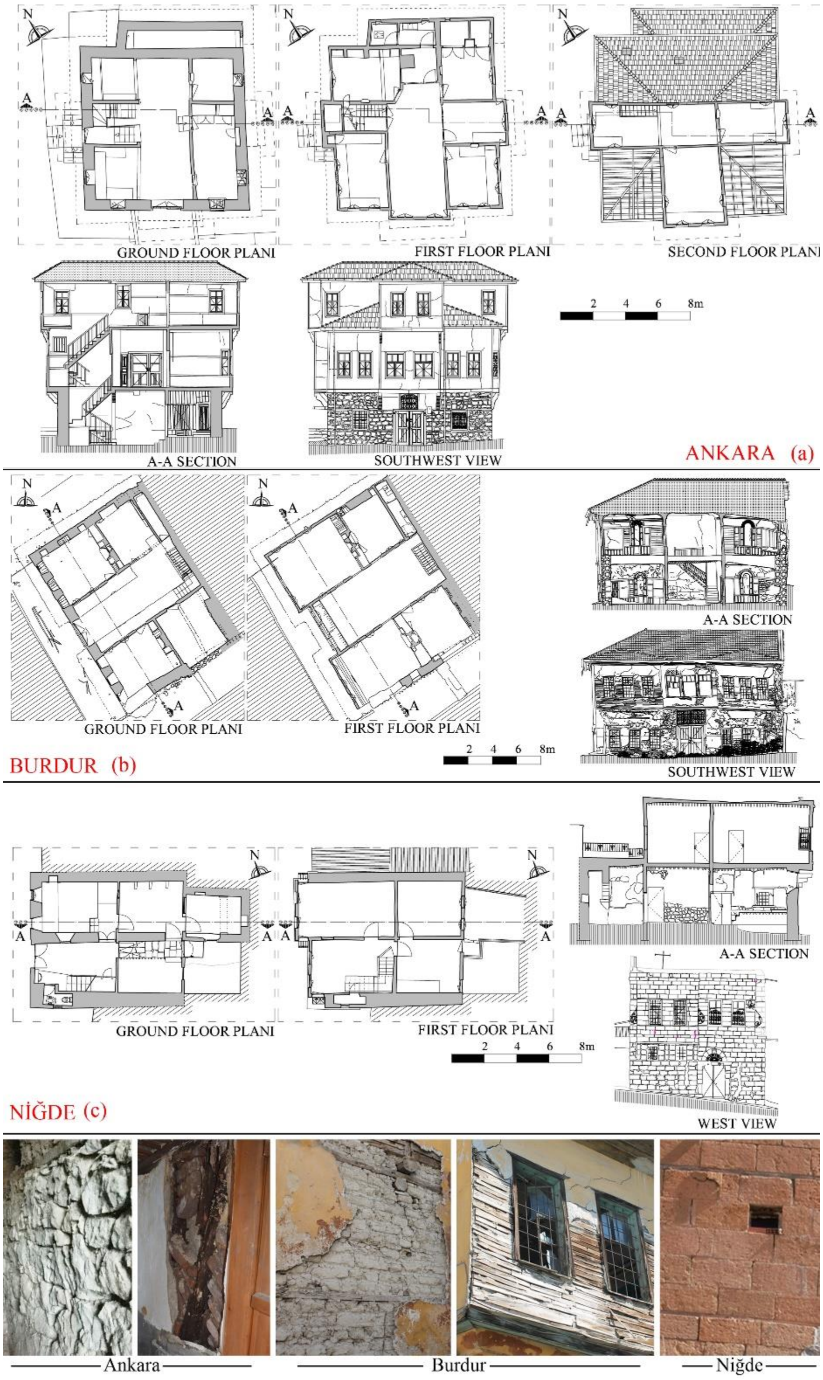


Figure 2. Construction systems Ankara Güdül residence (a), Burdur residence (b), Niğde residence (c)

Energy Efficient Scenarios

In this study, which aims to reveal how long the physical applications in the energy efficient improvement of historical buildings pay for themselves with the energy saving cost realized in the building, firstly, the interventions are scripted from small-scale interventions to large-scale interventions according to their physical effects. However, it is necessary to first analyze the current situation of the building in the context of energy efficiency, to understand the impact of applications in the context of energy efficiency. In this context, firstly, the current situation of the building was accepted as it is and it was scripted. In Scenario 1, only the insulation application on the roof slab was chosen, which does not require a major intervention. Scenario 2 was created by simply replacing the windows, with the potential to affect the exterior. In scenario three, these two scenarios were combined and roof slab insulation (10 cm of rock wool), window interventions (2 glazed window applications) were selected. In Scenario 4, the application of interior insulated wall insertion (5 cm rock wool) that requires interior wall interventions was chosen. In the context of cultural heritage protection, intervention methods that are accepted to be applied in historical buildings have been preferred in the literature compatible with the historical structure and in practices by conservation organizations. The content of the scenarios and their evaluation in the context of protection are explained in Table 1. In the evaluation of the applications in the context of historic building conservation, conservation organizations that worked in the context of energy efficiency in historical buildings were used (Url-4).

Table 1. Scenarios and assessment in the context of conservation (Url-4)

Scenarios	Selected Applications	Evaluation in the context of historic building conservation
THE CURRENT SITUATION	The current situation	-
Scenario 1	-Roof slab insulation (Rock wool 10 cm)	-The application of insulation on the roof does not affect the external appearance, and there are physical effects of moisture on the flooring and the structure. When appropriate harmless methods are used, it has less risk than window and interior insulation interventions. For this reason, only roof insulation was carried out in scenario 1.
Scenario 2	-Window interventions (3+12+3 mm double glazing application)	-Window interventions have the potential to adversely affect the exterior. Appropriate interventions should be made with cultural heritage by considering the external effects in detail. For these reasons, window interventions were determined as scenario 2.
Scenario 3	-Roof slab insulation (Rock wool 10 cm) -Window interventions (3+12+3 mm double glazing application)	-Scenario 3 is determined as two applications, window interventions and roof tile insulation, include the total impact of scenario 1 and scenario 2.
Scenario 4	-Adding an internal insulated wall (Rock wool 5cm)	-Internal insulation applications do not affect the external appearance, but have a significant effect on the moisture balance of the building envelope. It also has the potential to physically interfere with the building envelope in more areas than window and roof applications. For this reason, scenario 4, which includes interior insulation applications, has been determined as the 4th scenario, as it has a higher impact potential than window and roof covering applications.
Scenario 5	-Roof slab insulation (Rock wool 10 cm) -Adding an internal insulated wall (Rock wool 5cm)	-Scenario 5 was chosen as two applications, interior insulation and roof slab insulation, have more physical impact potential in total than the first four scenarios.
Scenario 6	-Roof slab insulation (Rock wool 10 cm) -Adding an internal insulated wall (Rock wool 5cm) -Window interventions (3+12+3 mm double glazing application)	-Scenario has been determined as under-scenario since it includes all applications determined within the scope of interior insulation, roof slab insulation and window interventions.

The thermophysical properties of the materials in the applications of the scenarios are given in table 2. In the table, the materials found in the structural elements of the 3 buildings selected for fieldwork are shown in their current state, and the U values (total thermal transmittance coefficient) of the main structural elements that make up the exterior walls, floor resting on the ground, roof covering and windows in the current conditions of the historical buildings are calculated and the calculated values are expressed in the table 2.

Table 2. The thermophysical properties of the materials used in the scenarios and the "U" values of their current state (Design Builder, 2022; Ecevit and Demirbilek, 1996; Ulukavak Harputlugil and Çetintürk, 2005; Ulu, 2018)

		Thermal conductivity coefficient (λh) (W/m K)	Density (kg/m³)	Specific Heat (j/kg K)	1.structure Gudul: Materials	1.structure Gudul: U value* (W/m² K)	2. structure Burdur: Materials	2. structure Burdur: U value *(W/ m² K)	3. structure Nigde: Materials	3. structure Nigde: U value *(W/ m² K)
Ground Floor Exterior Wall	**Lime Based Plaster(3 cm) (External)**	1	1800	840	-	1,57	+	0,79	-	2,77 - 1,51(Stone 69)
	Adobe (77 cm)	0,75	1730	880	-		+		-	
	Stone wall(65cm)	1,5	2180	720	+		-		-	
	Stone wall(24cm, 69cm)	1,5	2180	720	-		-		++	
	Lime Based Plaster (3 cm)	1	1800	840	+		+		+	
	Rock wool insulation (5 cm)(Internal)	0,033	710	100	-		-		-	
First and Second Floor exterior walls	**Lime Based Plaster(3 cm) (External)**	1	1800	840	+	2,53	+	1,40	-	3,12 - 1,38(Stone 59)
	Wood veneer (2 cm)	0,12	510	1380	-		+		-	
	Air gap (12 cm)				-		+		-	
	Brick(14 cm)	0,85	1500	840	+		-		-	
	Stone(18cm, 59cm)	1,5	2180	720	-		-		++	
	Wood veneer(2 cm)	0,12	510	1380	-		+		-	
	Lime Based Plaster (3 cm)	1	1800	840	+		+		+	
	Rock wool insulation with wooden frame system (5 cm)(Internal)	0,033	710	100	-		-		-	
Ground Floor	**Screed(Upside)(3 cm)**	0,41	1200	840	+	3,05	-	3,47	-	1,43
	Wood veneer (3 cm)	0,12	510	1380			-		+	
	Air gap (10 cm)						-		+	
	Cast concrete (5 cm)	1,13	2000	1000	+		-		-	
	Cast concrete (10 cm)	1,13	2000	1000	-		-		+	
	Soil (10 cm)(Bottom)	1,28	1460	880	-		+		-	
Ceiling	**Wood veneer (3 cm)(Upside)**	0,12	510	1380	+	1,01	+	1,01	-	1,46
	Stone wool insulation (10 cm)	0,033	710	100	-		-		-	
	Screed (5cm)	0,41	1200	840	-		-		+	
	Soil(22cm)	1,28	1460	880	-		-		+	
	Air gap (10 cm)				+		+		-	
	Wood veneer(3 cm)(Bottom)	0,12	510	1380	+		+		+	
Window	**Single clear glass(6mm)**	5,77								
	Low-e clear class (6mm-13mm-argon)	2,51								

1.bld.:Ankara Güdül dwelling, **2.bld.**: Burdur dwelling, **3.bld.:** Niğde dwelling
U value: Total thermal transmittance coefficient

Following these process steps, which materials are used in the calculations in the building envelope in all scenarios are shown in Table 3. The materials used for 3 buildings in the 6 scenarios determined here are shown.

Table 3. Building envelope physical properties of scenarios

		Scn1			Scn2			Scn3			Scn4			Scn5			Scn6		
		1. bld.	2. bld.	3. bld.	1. bld.	2. bld.	3. bld.	1. bld.	2. bld.	3. bld.	1. bld.	2. bld.	3. bld.	1. bld.	2. bld.	3. bld.	1. bld.	2. bld.	3. bld.
Ground Floor Exterior Wall	**Lime Based Plaster(3 cm) (External)**	-	+	-	-	+	-	-	+	-	-	+	-	-	+	-	-	+	-
	Adobe (77 cm)	-	+	-	-	+	-	-	+	-	-	+	-	-	+	-	-	+	-
	Stone wall(24cm,65cm,69cm)	+	-	+	+	-	+	+	-	+	+	-	+	+	-	+	+	-	+
	Lime Based Plaster (3 cm)	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
	Rock wool insulation (5 cm)(Internal)	-	-	-	-	-	-	-	-	-	+	+	+	+	+	+	+	+	+
First and Second Floor exterior walls	**Lime Based Plaster(3 cm) (External)**	+	+	-	+	+	-	+	+	-	+	+	-	+	+	-	+	+	-
	Wood veneer (2 cm)	-	+	-	-	+	-	-	+	-	-	+	-	-	+	-	-	+	-
	Air gap (12 cm)	-	+	-	-	+	-	-	+	-	-	+	-	-	+	-	-	+	-
	Brick(14 cm)	+	-	-	+	-	-	+		-	+		-	+		-	+		-
	Stone(18cm, 59cm)	-	-	+	-	-	+	-	-	+	-	-	+	-	-	+	-	-	+
	Wood veneer(2 cm)	-	+	-	-	+	-	-	+	-	-	+	-	-	+	-	-	+	-
	Lime Based Plaster (3 cm)	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
	Rock wool insulation with wooden frame system (5 cm)(Internal)	-	-	-	-	-	-	-	-	-	+	+	+	+	+	+	+	+	+
Ground Floor	**Screed(Upside)(3 cm)**	+	-	-	+	-	-	+	-	-	+	-	-	+	-	-	+	-	-
	Wood veneer (3 cm)	-	-	+	-	-	+	-	-	+	-	-	+	-	-	+	-	-	+
	Air gap (10 cm)	-	-	+	-	-	+	-	-	+	-	-	+	-	-	+	-	-	+
	Cast concrete (10 cm)	-	-	+	-	-	+	-	-	+	-	-	+	-	-	+	-	-	+
	Cast concrete (5 cm)	+	-	-	+	-	-	+	-	-	+	-	-	+	-	-	+	-	-
	Soil (10 cm)(Bottom)	-	+	-	-	+	-	-	+	-	-	+	-	-	+	-	-	+	-
Ceiling	**Wood veneer (3 cm)(Upside)**	+	+	-	+	+	-	+	+	-	+	+	-	+	+	-	+	+	-
	Stone wool insulation (10 cm)	+	+	+	-	-	-	+	+	+	-	-	-	+	+	+	+	+	+
	Screed (5cm)	-	-	+	-	-	+	-	-	+	-	-	+	-	-	+	-	-	+
	Compressed soil(22cm)	-	-	+	-	-	+	-	-	+	-	-	+	-	-	+	-	-	+
	Air gap (10 cm)	-	-	-	+	+	-	-	-	-	+	+	-	-	-	-	-	-	-
	Wood veneer(3 cm)(Bottom)	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
Window	**Single clear glass(6mm)**	+	+	+	-	-	-	-	-	-	+	+	+	+	+	+	-	-	-
	Low-e Double Generic Low-e clear class 6mm-13mm-argon)	-	-	-	+	+	+	+	+	+	-	-	-	-	-	-	+	+	+

1.bld.:Ankara Güdül dwelling, **2.bld.**: Burdur dwelling, **3.bld.:** Niğde dwelling

Modeling and Energy Simulation with Design Builder

In the study, the energy simulations were carried out with the Design Builder (Url-4) software, which was designed as the graphical interface of the Energy Plus calculation engine. In the program, the geometry of the buildings was modeled and the building envelope properties were determined. The latitude, longitude and climate data of the buildings were used from the Design Builder library based on the data of the provinces. The program includes climate data for the cities of Istanbul, Izmir and Ankara from Turkey. For this reason, analyzes were made on the basis of Ankara climate data for Niğde and Ankara Provinces, and İzmir climate data for the structure in Burdur province. The Design Builder Program analyzes the energy flow data according to the conditions defined in the program and the conditions in which the building is located, and the amount of heat gained and lost according to the hourly data, based on the specified constant indoor temperature. In these analyzes, energy flow calculations are made using hourly data of the year. Within the scope of the study, it is aimed to determine whether the interventions to be made in historical buildings in the context of passive applications will change the energy load. For this reason, the characteristics of the human density related to the heating load of the building, the properties of the lighting elements, the use of the building and the characteristics of the air conditioning systems were considered constant in all scenarios and the program's own data were used. Radiator heating was chosen as the heating system in all scenarios, and other data considered constant are given in the table below (Table 4).

Table 4. Data considered constant in all scenarios in the simulation program

Places	Heating temperature (°C)	Heating set point temperature(°C)	Illumination on the work plan (Lux)	Occupancy density (people/ m²)
Living room	21	12	150	0,0188
Bedroom	21	12	150	0,0229
Kitchen	18	12	150	0,0237
Hall	18	12	150	0,0155
HVAC				
Hvac type	**Heating system seasonal COP**	**Fuel type**	**Auxiliary energy (kwh/m²)**	
Radiator heating with gas	0,85	Natural gas	3,26	

Models were evaluated with the Design Builder simulation program within the framework of scenarios created to calculate payback periods. Data including annual heating loads and the amount of energy consumed per square meter were obtained. The visuals of the simulation are expressed in Figure 3.

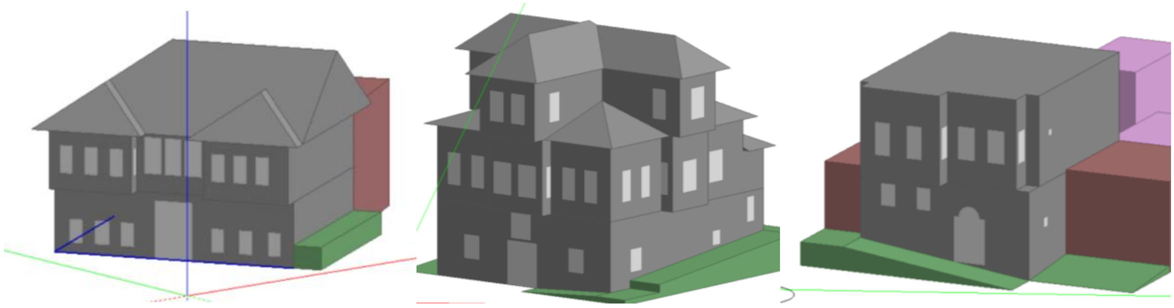


Figure 3. Simulation image of historical building, Burdur residence (a), Gudul residence (b), Niğde residence (c)

RESULTS AND DISCUSSION

In this area, heating load and cost, application intervention costs are determined and presented in tables.

Heating Load and Cost Analysis

In this section, the results obtained from the energy simulation study of three historical buildings selected from different climatic regions and their costs are explained and the scenarios relative to each other are discussed. In these data, the total energy consumption, heating load and carbon emission values according to the scenarios are calculated over the total values, the consumption and costs are expressed in table 5. The kWh energy costs of the companies in the regions where the buildings are located are taken into account in the cost calculations (Url-1, Url-2, Url-3). The heating costs obtained from the Design Builder program, the heating cost of the energy company in the region, and the unit price per kWh multiplied by the total heating costs were obtained (Table 5).

Table 5. Data considered constant in all scenarios in the simulation program

		Heating load (kWh/ m²-year)	Total heating load (kwh)	Heating cost ($/ kilowatt)*	Total heating cost ($)
1.building (Gudul)	**Current**	226	49.734	0,02221177	1.104,68
	Scn 1	211	46.502	0,02221177	1.032,89
	Scn 2	219	48.207	0,02221177	1.070,76
	Scn 3	204	44.943	0,02221177	998,26
	Scn 4	135	29.148	0,02221177	647,43
	Scn 5	117	25.307	0,02221177	562,11
	Scn 6	109	23.496	0,02221177	521,89
2.building (Burdur)	**Current**	56	15.532	0,02213462	343,79
	Scn 1	48	13.624	0,02213462	301,56
	Scn 2	53	14.886	0,02213462	329,50
	Scn 3	46	12.898	0,02213462	285,49
	Scn 4	46	12.701	0,02213462	281,13
	Scn 5	38	10.521	0,02213462	232,88
	Scn 6	35	9.657	0,02213462	213,75
3.building (Niğde)	**Current**	284	40.774	0,02620807	1.068,61
	Scn 1	257	36.881	0,02620807	966,58
	Scn 2	279	40.037	0,02620807	1.049,29
	Scn 3	252	36.128	0,02620807	946,85
	Scn 4	181	25.616	0,02620807	671,35
	Scn 5	148	20.969	0,02620807	549,56
	Scn 6	142	20.111	0,02620807	527,07
*According to the USD/TL selling rate data of the Central Bank of the Republic of Turkey dated 29/06/2022, 1 $ = 16,6991 TL					

As seen in Table 5, due to climatic differences, the highest energy consumption per square meter was observed in the historical building in Ankara (Gudul dwelling). This consumption is also reflected in the costs, and the heating cost of $1.104,68 has emerged in the current situation. In the current situation, an energy consumption of 226 kWh/m² per square meter has been observed in the building. This is followed by the historical building located in Nigde district with 58 kWh/m² increase in heating energy consumption per square meter and 284 kWh/m² energy consumption. The main reasons for the difference in heating energy consumption per square meter of these buildings located in similar climate types are the performance values of the building envelope. The highest decrease in energy consumption per square meter was observed in the building located in Burdur with an energy consumption of 56 kWh/m². Since the winters here are milder, a significant reduction in heating energy consumption is observed in the current situation. The reflection of this consumption on energy costs was realized as $343,79. In this structure, a significant reduction in heating costs is observed compared to other structures.

Implementation Cost

Cost is an important factor in renovation applications in historical buildings. In order to find payback periods within the scope of the study, the cost must be calculated. The following tables show the approximate costs of the scenarios determined. These costs are obtained from 2022 unit prices determined by official institutions (Ministry of Environment, Urbanization and Climate Change, Ministry of Culture and Tourism, General Directorate of Foundations, etc.) or from special exposures for applications not found here (Url-5, Url-6). The item number is the whole of the prices that includes the cost of all the construction costs (including the cost of materials, labor, etc.) in a certain unit from the beginning to the end of a work within the relevant official institutions in Turkey. In Table 6, the applications are summarized with their general outlines and code numbers. The reason for this is that all the application details will take up a lot of space, only the description of the transaction, the item number, the amount and the unit cost price are expressed in table 6 below. Details of the pose numbers can be found in the citations in the bibliography (Url-5, Url-6).

Table 6. Data considered constant in all scenarios

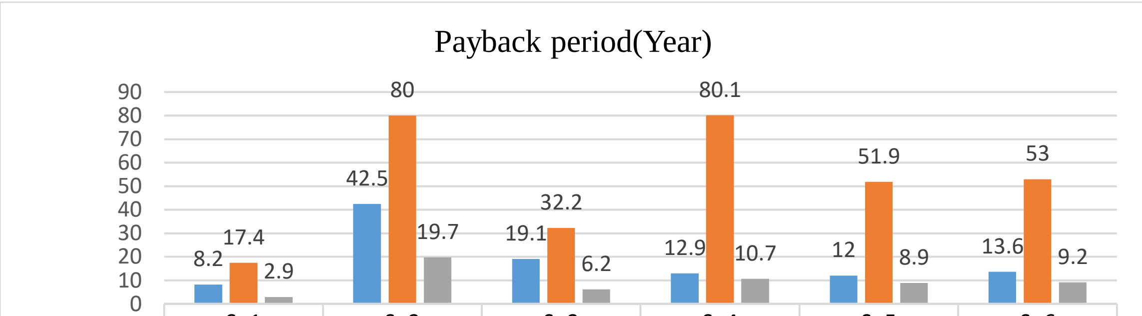
Buildings	Scenario	Definition	İtem number	Unit	Quantity	Unit Cost ($)**	Total Cost ($)	Scenario Total ($)
1.structure (GÜDÜL)	**Scn 1**	Insulation on the roof slab (10 cm rockwool)	15.340.1408*	m^2	148	3,97	587,56	**587,56**
	Scn 2	Double glazed window (3+12+3 mm)	15.470.1001	m^2	34	42,36	1.440,24	**1.440,24**
	Scn 3	Insulation on the roof slab (10 cm rockwool)	15.340.1408*	m^2	148	3,97	587,56	**2.027,80**
		Double glazed window (3+12+3 mm)	15.470.1001	m^2	34	42,36	1.440,24	
	Scn 4	Internal insulation (5 cm rockwool)	KTB.10.3004	m^3	4	631,96	2.527,84	**5.920,48**
			15.340.1003*	m^2	304	11,16	3.392,64	
	Scn 5	Internal insulation (5 cm rockwool)	KTB.10.3004	m^3	4	631,96	2.527,84	**6.508,04**
			15.340.1003*	m^2	304	11,16	3.392,64	
		Insulation on the roof slab (10 cm rockwool)	15.340.1408*	m^2	148	3,97	587,56	
	Scn 6	Internal insulation (5 cm rockwool)	KTB.10.3004	m^3	4	631,96	2.527,84	**7.948,28**
			15.340.1003*	m^2	304	11,16	3.392,64	
		Insulation on the roof slab (10 cm rockwool)	15.340.1408*	m^2	148	3,97	587,56	
		Double glazed window (3+12+3 mm)	15.470.1001	m^2	34	42,36	1.440,24	
2.structure (BURDUR)	**Scn 1**	Insulation on the roof slab (10 cm rockwool)	15.340.1408*	m^2	185	3,97	734,45	**734,45**
	Scn 2	Double glazed window (3+12+3 mm)	15.470.1001	m^2	27	42,36	1.143,72	**1.143,72**
	Scn 3	Insulation on the roof slab (10 cm rockwool)	15.340.1408*	m^2	185	3,97	734,45	**1.878,17**
		Double glazed window (3+12+3 mm)	15.470.1001	m^2	27	42,36	1.143,72	
	Scn 4	Internal insulation (5 cm rockwool)	KTB.10.3004	m^3	3	631,96	1.895,88	**5.020,68**
			15.340.1003*	m^2	280	11,16	3.124,8	
	Scn 5	Internal insulation (5 cm rockwool)	KTB.10.3004	m^3	3	631,96	1.895,88	**5.755,13**
			15.340.1003	m^2	280	11,16	3.124,8	
		Insulation on the roof slab (10 cm rockwool)	15.340.1408*	m^2	185	3,97	734,45	
	Scn 6	Internal insulation (5 cm rockwool)	KTB.10.3004	m^3	3	631,96	1.895,88	**6.898,85**
			15.340.1003*	m^2	280	11,16	3124,8	
		Insulation on the roof slab (10 cm rockwool)	15.340.1408*	m^2	185	3,97	734,45	
		Double glazed window (3+12+3 mm)	15.470.1001	m^2	27	42,36	1.143,72	
3.structure (Niğde)	**Scn 1**	Insulation on the roof slab (10 cm rockwool)	15.340.1408*	m^2	94	3,97	373,18	**373,18**
	Scn 2	Double glazed window (3+12+3 mm)	15.470.1001	m^2	9	42,36	381,24	**381,24**
	Scn 3	Insulation on the roof slab (10 cm rockwool)	15.340.1408*	m^2	94	3,97	373,18	**754,42**
		Double glazed window (3+12+3 mm)	15.470.1001	m^2	9	42,36	381,24	
	Scn 4	Internal insulation (5 cm rockwool)	KTB.10.3004	m^3	2,5	631,96	1.579,9	**4.258,30**
			15.340.1003*	m^2	240	11,16	2.678,4	
	Scn 5	Internal insulation (5 cm rockwool)	KTB.10.3004	m^3	2,5	631,96	1.579,9	**4.631,48**
			15.340.1003*	m^2	240	11,16	2.678,4	
		Insulation on the roof slab (10 cm rockwool)	15.340.1408*	m^2	94	3,97	373,18	
	Scn6	Internal insulation (5 cm rockwool)	KTB.10.3004	m^3	2,5	631,96	1.579,9	**5.012,72**
			15.340.1003*	m^2	240	11,16	2.678,4	
		Insulation on the roof slab (10 cm rockwool)	15.340.1408*	m^2	94	3,97	373,18	
		Double glazed window (3+12+3 mm)	15.470.1001	m^2	9	42,36	381,24	

*Special pose has been created based on the given pose number.
**According to the USD/TL selling rate data of the Central Bank of the Republic of Turkey dated 29/06/2022, 1 $ = 16,6991 TL

As seen in the Table 6, the costs vary in scenarios where similar applications are performed according to the size of the structures. In all scenarios, the lowest cost is observed in roofing insulation. The highest cost occurs in interior insulation applications due to the excess application area (Table 6). Although the costs of interior insulation applications are high, they provide a serious reduction in energy savings. While window applications increase the cost significantly based on the applied area, they do not cause a significant reduction in energy consumption. In direct proportion to the size of the building, the highest application cost was realized in the building located in Güdül district. After that, the structures in Burdur and Nigde come. With the analyzes carried out, it was ensured that the cost analyzes used in the payback period calculations were revealed.

Calculation of Pay Back Period

Cost is an important parameter that cannot be ignored in applications carried out in buildings. In this context, the payback periods of the applications carried out in the buildings are of great importance in terms of the preference of the applications. Applications that pay for themselves in a shorter time are more advantageous than applications that provide recycling in the longer term. In the study, which aims to determine how long the physical applications carried out in the energy efficient improvement of historical buildings will pay for itself with the energy saving cost realized in the building, in this section, it has been determined that which applications pay for themselves in the scenarios (Graphic 1).



	Sn1	Sn2	Sn3	Sn4	Sn5	Sn6
GÜDÜL	8.2	42.5	19.1	12.9	12	13.6
BURDUR	17.4	80	32.2	80.1	51.9	53
NİĞDE	2.9	19.7	6.2	10.7	8.9	9.2

Graphic 1. Findings in terms of depreciation

Generally, the payback period is the lowest in the structure located in Nigde province, which has the highest heating load. While the longest payback period for the building in Nigde is 9.2 years in scenario 6 with interior insulation, insulation in roofing, and double-glazed window applications, the shortest payback period is 2.9 years in scenario 1, where roof insulation is applied. In the building located in Burdur province, which has the lowest heating load, the payback period is the highest among the selected buildings. While the longest payback period in Burdur is 80.1 years in scenario 6 with interior insulation, insulation in roofing, double-glazed window applications, the shortest payback period is 17.4 years in scenario 1, where roof insulation is applied. As can be seen from these findings, it is seen that interventions are more effective in terms of energy saving in buildings located in cold climate regions. At the same time, payback periods are shorter. As seen from the scenarios, the intervention styles also affect the payback periods. The applications with the shortest payback period in all scenarios were in the roof slab insulation. In scenario 1, where the insulation on the roof slab is realized in all buildings, the payback periods were realized in Niğde (2.9 years), Güdül (8.2 years) and Burdur (17.4 years), respectively. Due to the flat roof and excess heat losses in Niğde, the insulation application was the most effective scenario in terms of energy savings and payback period (2.9 years). In Burdur (17.4 years), which has a lower heating load in a milder climate, the payback period of the roof application has increased even more compared to the structures located in Niğde (2.9 years) and Güdül (8.2 years). With all these data, there are also differences in the relationship between building heating load savings and payback periods in scenarios according to the current situation. The relationship between energy load and payback periods in scenarios is expressed in Table 7.

Table 7. Data considered constant in all scenarios in the simulation program

Scenarios		Güdül	Burdur	Niğde
SCN.1	Payback period(Year)	**8,2**	**17,4**	**2,9**
	Percent (%) energy savings compared to the current situation	7	14	10
SCN.2	Payback period(Year)	**42,5**	**80**	**19,7**
	Percent (%) energy savings compared to the current situation	3	5	2
SCN.3	Payback period(Year)	**19,1**	**32,2**	**6,2**
	Percent (%) energy savings compared to the current situation	10	18	11
SCN.4	Payback period(Year)	**12,9**	**80,1**	**10,7**
	Percent (%) energy savings compared to the current situation	40	18	36
SCN.5	Payback period(Year)	**12**	**51,9**	**8,9**
	Percent (%) energy savings compared to the current situation	48	32	48
SCN.6	Payback period(Year)	**13,6**	**53**	**9,2**
	Percent (%) energy savings compared to the current situation	52	38	50
SCN.:Scenario				

Here, energy savings should be taken into account as well as payback periods. For example, as can be seen in Table 6, in scenario 1, which includes insulation on the roof in the province of Niğde, which has the lowest payback period, the payback period is 2.9, while the energy saving is 10 percent compared to the current situation. In the same structure, in scenario 6, 50 percent energy savings are realized, while the payback period is 9.2 years. Here, there is a need for optimization methods in the context of energy savings and payback periods.

CONCLUSION

In this study, which aims to determine how long the physical applications in the energy efficient renovation of historical buildings will pay off with the energy saving cost in the building, it has been concluded that the payback periods may be too much in similar applications in buildings located in regions with different climatic characteristics. While energy efficiency applications are very short in climatic regions with cold winters and high heat losses, it has been observed that depreciation processes are very high in climates with mild winters. It has been determined that the payback period of roof insulation applications in buildings located in regions with cold winters is very short. It has been revealed that interior insulation applications in these regions significantly reduce the payback periods with significant energy savings. In addition, it was concluded that double glazing applications in the selected structures greatly increased the amortization period. In this context, insulation and interior insulation applications can be carried out on the roofing in regions with cold winters, with more affordable cost and payback period. In hot climate regions, although the applications provide significant energy savings, the payback periods are too long. In hot climate regions, applications are not effective in terms of payback period. In addition, significant effects are observed between heating energy saving values and payback periods. Although the insulation in the roof slab provides a low payback period, it cannot save as much energy as the interior insulation. In this context, a balancing problem arises between heating energy saving values and payback periods. Studies involving optimization solutions to solve this problem can be carried out in future studies.

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