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Research Article

Simulation-supported energy retrofit in historic educational buildings: Ziya Gökalp Elementary School

Asst. Prof. Dr. Ruşen Ergün[1*]

[1]Dicle University, Faculty of Architecture, Department of Architecture, Diyarbakır, Türkiye.
rusen.ergun@dicle.edu.tr

*Corresponding Author

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Abstract

Energy retrofitting of historic buildings is important for sustainability. However, this is a difficult task due to regulations aimed at preserving historical values. This study aims to develop energy retrofit strategies for the 20th-century Ziya Gökalp Elementary School built as a type of project during Ottoman educational reforms. The method is predicated on a comparative analysis of the model created using DesignBuilder simulations, examining both the current state and retrofit scenarios. Energy performance retrofit scenarios have been developed with consideration for national and international guidelines, local climate conditions, and the building's cultural heritage value. Energy retrofit recommendations were made for the walls, attic floor, and window components. Energy, carbon emission and thermal comfort analyses were conducted for the current state of the building and proposed scenarios. As a result of the proposed scenarios, it was determined that energy conservation was achieved at a rate of 72.43%, the number of comfortable days increased by 31%, and operational carbon emissions decreased by 10.39%. It has been determined that the increase in embodied carbon can be offset by a decrease in operational carbon within two years. These results show that energy retrofits can be conducted without damaging historic educational buildings.

Keywords: Historic building, Energy retrofit, Building simulation, Thermal comfort, Carbon emission

Extended Abstract

Introduction: The building sector is responsible for approximately 40% of total energy consumption and 36% of CO^2 emissions, and its impact on climate change is significant. Furthermore, it is estimated that approximately 85% of buildings in use in 2050 will be existing structures. This underscores the efficacy of energy retrofitting as a pivotal strategy for promoting sustainability within the building sector. Given that historic buildings constitute 30-40% of the building stock in the European Union, the implementation of energy retrofitting in such structures is of paramount importance. It is evident that a significant number of European Union countries have recognized the pivotal role of energy retrofitting historic buildings in achieving the 2050 sustainability targets. In this context, a guide for energy retrofitting of historic buildings was published in 2017, and energy retrofitting of these buildings was encouraged.

Purpose and scope: A paucity of research has been conducted about energy efficiency in historic educational buildings. The objective of this research is to develop an approach that will reduce energy consumption in historical educational buildings constructed in the 20th century. The Ziya Gökalp Primary School in Diyarbakır, which is in Türkiye's hot and arid climate zone and continues to operate as an educational institution, was selected as the application area for the study. This study represents the inaugural research to be conducted specifically on historical educational buildings in Türkiye's hot and arid climate zone. It is hypothesized that the findings will contribute to the resolution of a significant lacuna in the extant literature on the energy retrofitting of historical educational buildings.

Method: The research is founded upon a comprehensive approach that combines quantitative and qualitative methods. In accordance with this approach, a comprehensive program of research was conducted in stages, encompassing literature reviews, archival research, field observations, on-site measurements, and energy analyses using a dedicated energy analysis program. A comprehensive literature review was conducted using the Web of Science and Scopus databases. A thorough evaluation of the extant literature identified the subject's strengths and weaknesses. The primary objective of ascertaining the strengths was to determine the most efficacious strategies for the renovation of historic buildings, while the primary objective of identifying the weaknesses was to contribute to the ongoing discourse. Ten studies were identified in searches conducted in the Web of Science database using the specified keywords. Seventy-eight studies were identified

in searches conducted in the Scopus database using the same keywords. Twenty of these studies were excluded as they were in different disciplines. When both databases are evaluated together, it is evident that most studies focus on thermal comfort analysis in historic school buildings or on energy retrofitting of non-historic educational buildings. It has been determined that the number of studies on the energy retrofitting of historic educational buildings is quite limited. It is understood that most of the existing studies focus on buildings constructed in the 20th century and that the research is generally conducted in cold or hot-humid climate regions. These studies frequently include recommendations for improving energy efficiency by enhancing the performance of exterior walls, basement walls, roof and attic insulation, and windows. In this scope: improvements to the interior walls, roof, and windows of the historic building, which is the subject of the current study, have been proposed. DesignBuilder Software Version 7 was utilized for energy analysis. On-site measurements were taken to calibrate the software. The calibration process involved the utilization of a Micro Lite USB Data Logger 5016 temperature sensor. The Root Mean Square Error Coefficient of Variation (CV(RMSE)) and Mean Error (MBE) were utilized in conjunctions to ensure calibration. Furthermore, the requisite information was collected on site through the utilization of observation techniques, photographic documentation, and direct interviews. Improvements to the interior walls, roof, and windows of the historic building, which is the subject of the current study, have been proposed.

Findings and conclusion: The implementation of the proposed scenarios resulted in a 72.43% reduction in energy consumption, a 31% increase in the number of comfortable days, and a 10.39% decrease in operational carbon emissions. It has been calculated that the increase in concrete carbon resulting from the applications can be balanced by a reduction in operational carbon within approximately two years. The findings demonstrate that energy renovation interventions are possible without damaging the original values of historic educational structures.

Keywords: Historic building, Energy retrofit, Building simulation, Thermal comfort, Carbon emission

INTRODUCTION

The energy crisis that emerged in the late 1970s has led countries to reduce their energy consumption. The building sector accounts for 40% of total energy consumption and 36% of carbon emissions (IEA, 2021; UNEP, 2020). Energy retrofitting of constructed buildings is important for reducing energy consumption and carbon emissions. It is estimated that existing buildings will account for approximately 80-90% of the building stock in 2050 (Angrisano et al., 2021: 4). This shows that a significant portion of the energy consumed and to be consumed already comes from existing buildings (Power, 2008: 4487). However, only 1-3% of existing buildings are retrofitted for energy each year. This shows that the energy retrofitting of existing buildings is insufficient (Ali & Hashlamun, 2019: 1). The European Commission has published various regulations aimed at increasing the energy efficiency of existing buildings. However, the first three of these regulations state that historic buildings may be exempt from energy retrofitting due to their special architectural value or their status as part of a specific environment (Directive 2002/91/EC, n.d.; Directive 2010/31/EU, n.d.; Directive 2012/27/EU, 2012). In addition, many building energy efficiency regulations have ignored the energy retrofit of historic buildings (Martínez-Molina et al., 2016). Approximately 30-40% of the building stock in Europe consists of historic buildings. This shows that energy retrofitting of historic buildings is crucial for achieving the European Green Deal 2050 (Buda et al., 2022; European Commission, 2016; Ruggeri et al., 2020). Many European countries have also recognized that energy retrofitting historic buildings is important. (Martínez-Molina et al., 2016: 82).

In response to this situation, the European Committee for Standardization (CEN) published a guide in 2017 (EN 16883, 2017). EN 16883 aims to assist in making the best decisions to improve the energy performance of historic buildings without compromising their value, through interdisciplinary planning (Leijonhufvud, 2021). The lack of insulation in exterior walls, the use of non-standard materials, and the complexity of physical characteristics due to traditional construction methods, as well as the necessity of interventions to comply with conservation principles, are the main challenges in the energy retrofitting of historic buildings (Webb, 2017: 749). The European Commission states that reference buildings can be selected for the national building stock in the energy upgrading of historic buildings. It has been specified that criteria such as building age, building size, construction material, user type, and climate zone should be considered in selecting reference buildings (European Commission, 2012). Studies can be conducted by selecting one or more reference buildings for the building stock (Ruggeri et al., 2020; Timur et al., 2022) Ruggeri et al. (2020) selected a building representing the building stock of War Wounded Houses in Italy) and conducted analyses within the scope of this building (Ruggeri et al., 2020). Timur et al. (2022) analyzed one reference building each from rural and urban areas of Muğla in their study on the traditional Turkish house with an outer hall (Timur et al., 2022). The building to be retrofitted does not have to be representative of stock. Energy retrofitting can also be carried out on a single building (Kyritsi et al., 2025; Šekularac et al., 2020; Ziozas et al., 2024). It can be said that studies on energy retrofitting of historic buildings are generally specific to individual buildings (Lidelöw et al., 2019: 239). It can be said that passive measures are primarily taken in studies related to the energy retrofitting of historic buildings (Burattini et al., 2015). In this context, recommendations were made for the building envelopes, such as wall and roof, reinforcing window openings, and window shutters (Ali & Hashlamun, 2019; Cho et al., 2020; Kolokotsa et al., 2009; Kyritsi et al., 2025; Loukaidou et al., 2017; Ziozas et al., 2024). Insulation recommendations for historic buildings are focused on the inner surface of the external wall and roofs. The main reason for this is that the outer surface of exterior walls often has special details (Webb, 2017). The fact that the visual loss in the historic building cannot be compared to energy savings explains this situation (Šekularac et al., 2020: 3). It can be said that different materials are used in wall insulation. In this context, it can be said that insulation materials such as XPS, EPS, calcium silicate boards, rock wool, aerogel, cork lime, and hemp lime timber boards are used (Ali & Hashlamun, 2019; Etxepare et al., 2020; Walker & Pavía, 2015). Recommendations for window openings generally focus on energy-efficient glass choice, double glazing or window film installation (Burattini et al., 2015; Moghaddam et al., 2021; Timur et al., 2022). In addition, there are various studies recommending window replacement or window frame reinforcement on building facades. These studies generally recommend window materials that will not change the external appearance of the building (Ziozas et al., 2024). In addition to the building envelope, the effect of fuel change on energy conservation was also investigated. Şahin et al. (2015) analyzed the impact of energy sources such as fuel oil and electricity on the energy retrofitting of historic buildings (Şahin et al., 2015).

Literature reviews suggest that buildings recommended for energy retrofitting were generally constructed in the 20th century. The fact that most of these are still in active use makes it possible for the recommended strategies to achieve effective results in the short term in terms of energy savings and thermal comfort. This situation can be considered the main reason for offering recommendations specifically for buildings constructed in the 20th century (Lidelöw et al., 2019; Martínez-Molina et al., 2016). Martinez-Moline et al. (2016) noted that research on energy retrofits in historic buildings has focused on building types such as residential buildings, religious structures, museums, and theatres (Martínez-Molina et al., 2016: 74). It has been noted that academic buildings and palaces are among the least studied building types in the field of energy retrofitting of historic buildings (Butera et al., 1985; Sauchelli et al., 2014). Ten studies were identified in searches using the Web of Science database with the codes ((TS= (“energy retrofit” OR “energy efficiency” OR “energy rehabilitation” OR “energy intervention” OR “energy restoration” OR “energy refurbishment” OR “energy saving”)) AND TS= (“historic” OR “traditional”) AND TS= (“education building” OR “school building”). The same keywords were searched in the Scopus database using the “Article title, abstract, keyword” filter. Within this scope, seventy-eight studies were identified. Twenty of the studies identified in the Scopus database were excluded because they were in fields such as “Mathematics,” “Computer Science,” and “Chemical Engineering.” A significant part of the studies identified in the Web of Science and Scopus databases are aimed at determining the thermal comfort analyses of historic school buildings or the energy retrofitting of non-historic educational buildings (Carlos, 2016; De Santoli et al., 2014; Salvalai et al., 2017; Yang et al., 2016) A few studies have been identified that focus on the energy retrofitting of historic educational buildings (Baggio et al., 2017; Buvik et al., 2014, 2015; Jerominko & Cichowicz, 2025; Park et al., 2025; Run et al., 2023). It can be said that these studies generally focus on buildings constructed in the 20th century. The climate zones where the studies were conducted are cold or hot and humid climates. It can be said that these studies generally propose recommendations for wall, roof and attic insulation, and window glass reinforcement (Table 1).

Table 1. Summary of literature on energy retrofit in historic educational buildings

(Butera et al., 1985)	Case study: twenty-nine historic school buildings found in the Palermo region of Italy
	Retrofitting recommendation: Smart indoor temperature control systems + insulation inner surface of the external wall
	Case study: High school building constructed in the Varese region of Italy in the 1960s

(Sauchelli et al., 2014)	Retrofitting recommendation: Hypotesis 1: Use of added external glazing facade + Use of double glazing with the addition of internal glazing+ Replacement of all windows with highly insulated and high-performance windows, Hypotesis 2: external wall insulation, Hypotesis 3: Roof insulation + Mechanical ventilation + replacement window
(Buvik et al., 2014, 2015)	Case study: 1914 Brandengen Primary School in Norway
	(Buvik, 2014) Retrofitting recommendation: Passive house window (they were not the original windows in the building- replaced in 1965) + Attic floor insulation + Waterproofing and thermal insulation of the basement wall + Ground source heat pump + Building energy management system
	(Buvik, 2015) Retrofitting recommendation: Mineral woll insulation on the floor and walls of the attic floor + Drainage of the basement floor wall + Replacement of non-original windows with passive house windows + Replacement of original windows with E-glasses + Addition of a heat pump to the external environment
(Run et al., 2023)	Case study: University of Technology buildings built in France in the late 1960s
	Retrofitting recommendation: External wall insulation + argon 16mm filled double glazing + Rock wool insulation (120mm) + Mechanical ventilation+ district heating+ radiator and thermostat-controlled heating
(Park et al., 2025)	Case study: An educational building built in 1930 in Jinju, South Korea
	Retrofitting recommendation: New roofing instead of Asphalt Shingle + Replacement of aluminum window and door frames with wooden frames + Replacement of 3 mm single glazing with 24 mm low-emissivity double glazing + Adding PF insulation board to the walls.
(Jerominko & Cichowicz, 2025)	Case study: An insulated educational building built in Poland in the 1970s
	Retrofit recommendation: replacing the old coal boiler (the current heat source) with gas absorption heat pumps and a condensing boiler + Adding an independent ventilation system according to the usage programs of the classrooms and the number of users + Adding PV on the roof of the building + Replacing the lighting elements with LED lighting systems

Within the scope of the literature review, it can be said that there are very few studies on energy retrofitting of historical educational buildings. The aim of this study is to present an approach to energy retrofitting of historic educational buildings built in the 20th century. In the study, Ziya Gökalp Primary School building in Diyarbakır, which is in the hot and arid climate zone of Türkiye and continues its educational function, was selected as the reference building. This is the first study on historical educational buildings in Türkiye and in a hot and arid climate zone. It is thought that this study will partially fill an important gap in the literature on energy retrofitting of historic educational buildings. The materials section of the study examines the typical characteristics of educational buildings constructed as type projects during the Ottoman period, the climatic and geographical conditions of Diyarbakır, and the architectural features and structural components of the Ziya Gökalp Primary School. The methods section includes the literature review methodology, the procedures and durations of on-site measurements, descriptive information regarding the DesignBuilder software, the model calibration process and the formulas used, as well as explanations about thermal comfort and carbon emission analyses. "Findings" section encompasses the calibration process, in addition to the analysis results and evaluations concerning building components, energy consumption, CO2 emissions, and thermal comfort.

MATERIAL

In the post-Tanzimat period, the Ottoman Empire strategically emphasized the development of physical learning environments to modernize educational infrastructure as part of its Westernization reforms (Kodaman, 1991). In this context, school projects from various parts of Europe, particularly France, were compiled. These projects were built as type projects for various levels of education in the Ottoman Empire in many places such as Diyarbakır, Kayseri, İstanbul, Mardin, Kırşehir, etc (Türkmen, 2022). The educational buildings constructed are similar in terms of plan typology, thick walls, geometry, symmetrical design, facade arrangement and building construction materials. Interior designs are generally in a linear classroom arrangement around a singular corridor. Window and door openings are usually symmetrically arranged and arched (Ergün & Halifeoğlu, 2023; Parlak, 2018). Ziya Gökalp Primary School in Diyarbakır is one of the educational buildings built as a type of project in the post-Tanzimat period (Ergün, 2024; Ergün & Halifeoğlu, 2023).

Diyarbakır

It (37°55' N, 40°12' E) is in the Southeastern Anatolia region of Türkiye, between Karacadağ mountain and the Tigris River, within the Al Jazeera region. The historical settlement, including the Ziya Gökalp Primary School, is bounded by the Diyarbakır Fortress. "Diyarbakır Fortress and Hevsel Gardens Cultural Landscape" was registered in the UNESCO World Heritage Convention in 2015 (UNESCO World Heritage Convention, 2015). June, July, August, and September are the hottest months of the year, and the city is in a hot and dry climate zone (Figure 1) (Meteoroloji Genel Müdürlüğü, 2026).

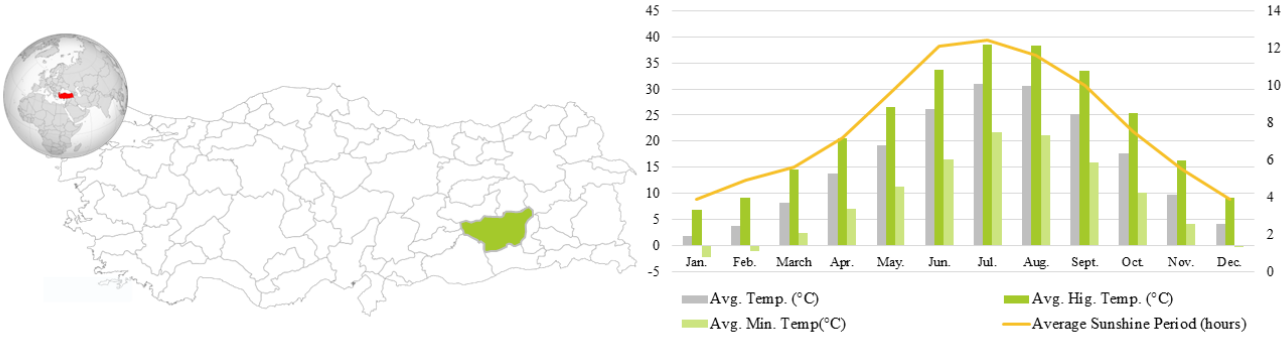

Figure 1. Diyarbakır's location and climate data

Ziya Gökalp Primary School

It is thought to have been built in the 1910s during the post-Tanzimat period (Baydaş, 2007). The building is an educational building registered in 1980 (Diyarbakır Regional Board of Cultural Heritage Conservation, 1980). The building continues to function for educational purposes. The total area of the building actively used is 740m². The total building area is 1153m² with a basement floor + 2 floors. The basement floor is not actively used and is closed. The school measures 2420*1670. The building extends in the north-south direction, making an angle of about 5° with the north (Figure 2). The school originally had two doors, a garden and the main entrance. As a result of the interventions, a window on the east façade was changed into a garden door. The main entrance of the building is on the west façade, and the original garden door is on the south facade (Figure 2). The building's survey, restitution and restoration projects and detailed information are given in ref (Ergün, 2024).

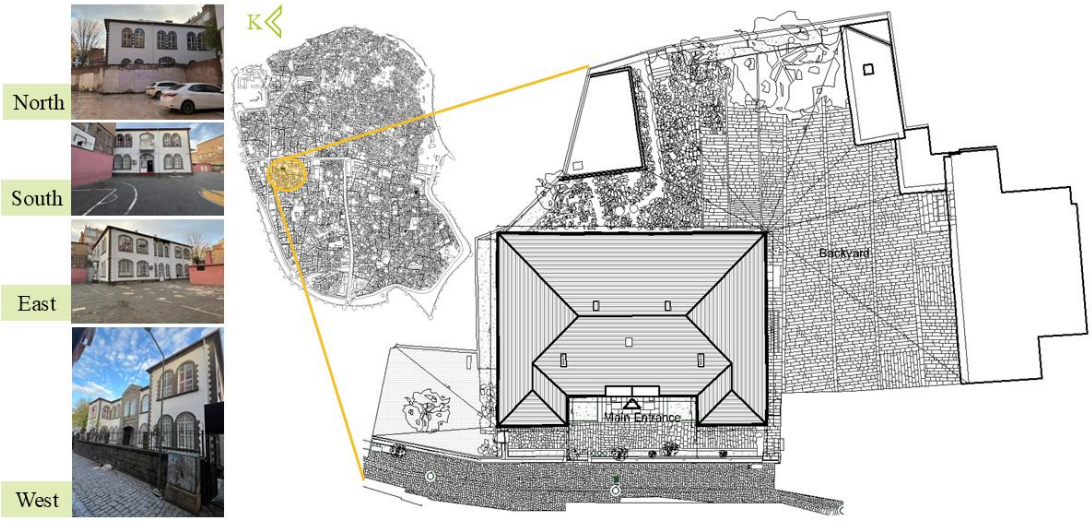

Figure 2. Ziya Gökalp Primary School

There are six classrooms in the school. The classrooms are located on the ground (2 classrooms) and first floor (4 classrooms). Classrooms have a total area of approximately 265m². The floor height of the classrooms is 4m. The average density of the classrooms is 1.2 people/m². At least two walls of all classrooms are designed as exterior walls. The total number of windows in 6 classrooms is 29. There is also one balcony in classroom 1-05. The window-to-wall ratio (WWR) in the classrooms is approximately 25% (Figure 3).

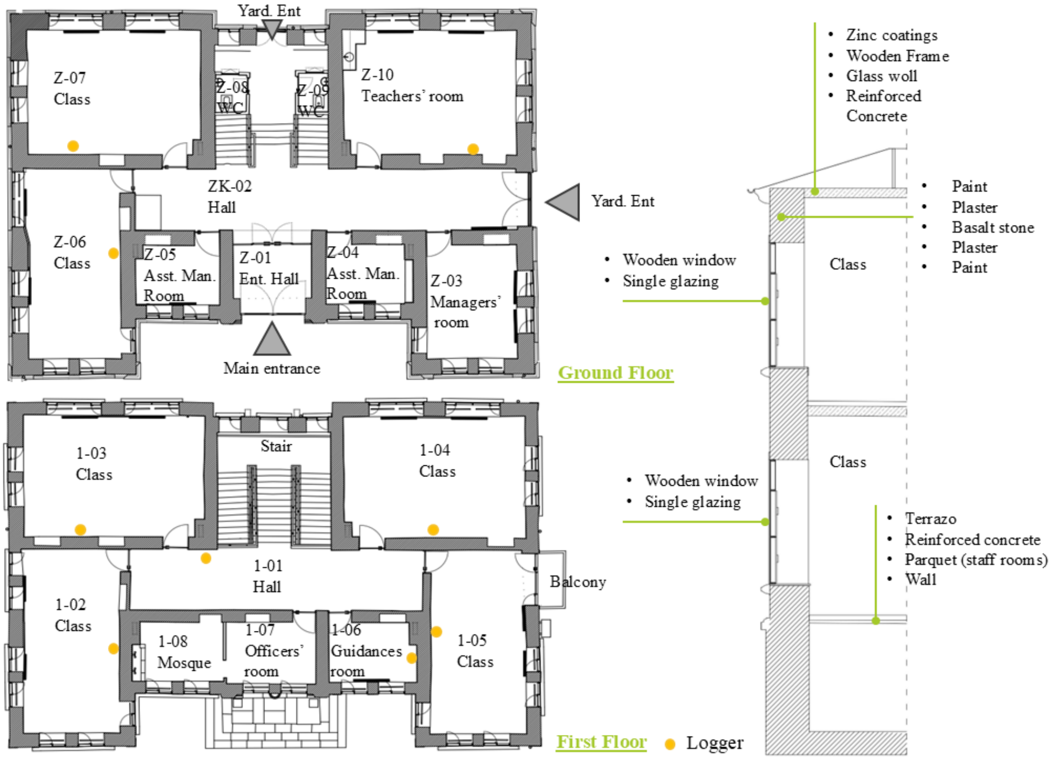

Figure 3. Floor plans and building components.

The school is used for educational purposes from 07.00 to 18.00. The school has approximately 550 students and 46 teachers. Approximately 220 students and twenty-two teachers use the building between 07.00-12.30, while the rest of the students and teachers use the building between 12.40-18.00. The school is closed for summer vacation each year from June 15 to September 15.

Building components

The building was restored in 1962 (Baydaş, 2007: 131). The original building components of the building before the restoration and the current building components were obtained from the measured drawing project The Prime Ministry Republican Archives (1933), project drawings of the period architecture for the 20th century educational buildings and field studies (Table 2).

Table 2. Original and existing building components

Component	**Original (1912-1962)**	**Existing (1962-)**
Exterior wall		Paint + plaster + masonry + plaster*+paint*
Roof	Wooden frame + Roof tiles	Wooden frame* + Membrane* + Galvanized sheet metal*
Attic floor	20cm wooden beam +2cm wooden covering	Concrete slab (20cm) * + glass wool*
Floor	20cm wooden beam +2cm wooden covering	Concrete slab (20cm) * + terrazo*
Window	8-division wooden framed window+ Clr single glazing	6-division wooden framed window+ Clr single glazing
Window jamb	2 cm thick basalt stone	2 cm thick basalt stone
Main entrance door	Wooden	Wooden *
Interior doors	Wooden	Wooden *

* Refers to modified components. Note: Administrative rooms also have parquet flooring.

In the existing building, the walls are not insulated. The attic of the building is not used (cold roof). The roof is galvanized sheet coating. No heat insulation material is used under the galvanized sheet coating. Attic floor is covered with glass wool on reinforced concrete. The flooring of the spaces is reinforced concrete slab and terrazzo coating. The floor in the manager's room, assistant manager's room, teachers' room, guidance room and masjid is covered with parquet (Figure 4).

Figure 4. Classroom, Masjid, Manager room, Building entrance, Classroom window, Manager room door

All the windows are single glazed with wooden frames. There are no shading elements other than 2cm jambs. All interior doors are made of wooden material. The original main entrance door has been conserved. Windows are used for natural ventilation in classrooms (Figure 4). Electricity and coal are used as energy sources in the building. Coal is used for heating, and electricity is used for lighting. A coal boiler is used for heating. The water heated by the boiler is distributed to 60x150cm radiators to provide heating.

METHOD

The aim of the study was to propose energy efficiency improvements without causing damage to the original components of the historic building. The identification of the original components of the historic building was achieved through archival research and fieldwork. A comprehensive review of the relevant literature was conducted to ensure the correct implementation of the proposed improvements to the building. Calibration analyses were performed to ensure consistency between the simulation model and the actual characteristics of the building. The DesignBuilder Software was used for the purposes of energy analysis, thermal comfort analysis, and CO2 emission analysis. Within this scope, the study is based on a multi-dimensional method using a combination of quantitative and qualitative methods. In this context, literature reviews, archival research, field studies, on-site measurements, DesignBuilder software (Figure 5).

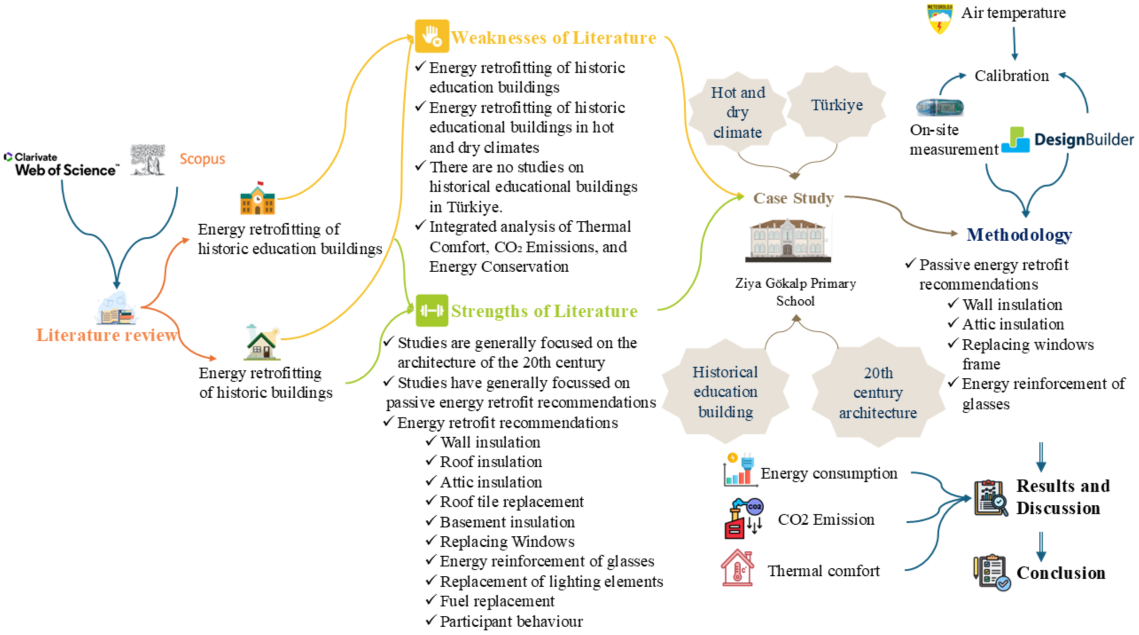

Figure 5. Research process

Literature Review Procedure

In the first stage, the literature was reviewed. Web of Science and Scopus databases and archival research were used in the literature review. In this context, energy retrofits of historic buildings and historic educational buildings were investigated. Based on the data obtained, the strengths and weaknesses of the literature were identified. Given the weaknesses in literature, this study aims to contribute to it. In this context, historical educational buildings in Türkiye, energy retrofitting of historical buildings in hot and dry climates, carbon emissions, and gaps in thermal comfort integration were identified. In this context, the aim was to contribute to the literature through integrated analyses. By identifying the strengths of the literature, the right strategies for energy retrofitting of historic buildings can be determined, as well as the historic building to be selected. In this context:

- Selecting a 20th-century educational building in a hot and dry climate as a field study,
- Adding insulation to the inner surface of the external wall
- Adding insulation to the attic floor,
- Replacement of windows

All proposals are within the scope of passive strategies, and no mechanical systems are proposed (Figure 3). The recommendations are directly linked to literature reviews, Türkiye-Thermal Insulation Requirements in Buildings (TS 825) project guidelines, EN 16883:2017, field study, international heritage conservation charter and building requirements. TS 825 is prepared according to European standards and specifies the minimum thermal insulation values of buildings in Türkiye. According to these rules, the energy efficiency of buildings in Türkiye is close to the energy efficiency of buildings in European countries (Diz, 2024). It is a legal obligation to be applied in various buildings such as education and training buildings (Republic of Türkiye Ministry of Environment Urbanization and Climate Change, 2025; Turkish Standards Institute, 2008, 2024). The main reason for using TS 825 standards is to ensure the functional sustainability of the existing building.

On-Site Measurement

As part of the on-site measurements, the indoor air temperature was measured with a Micro Lite USB Data Logger 5016 temperature logger. The temperature recording range of the logger is between -40°C and 80°C (Fourtec, n.d.). A total of 9 loggers, one in each classroom, guidance room, teachers' room and first floor corridor. The loggers were placed at a height of 1.1 meters as recommended in American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc (ASHRAE) Standard 55-2013. Measurements were taken between 27.05.2025 hours: 18.00- 30.05.2025 hours: 16.00 every 15 minutes for 70 hours. In addition to physical measurements, observation, photography and face-to-face interview techniques were also utilized in field study. Field studies played an important role in determining the criteria such as the active usage periods of the school, the duration of the open windows, the average density of the classrooms, and the general clothing combinations of the users for determining the clothing insulation (clo) values. The main purpose of the holistic study of the building is to ensure the calibration between simulation and real building data.

Designbuilder Software Analysis

Designbuilder software with Energy Plus engine was used for the analysis. Designbuilder is a validated program according to ANSI/ASHRAE Standard 140-2023 Building Thermal Envelope and Fabric Load Tests using the BESTEST procedure for validation of building energy simulation programs (Designbuilder Sofware, 2025). This simulation software can calculate energy consumption for heating and cooling, carbon emissions, thermal comfort-PMV values, and lighting. DesignBuilder software was used in four stages in the study. In the first stage, it was used in the calibration process of the real building and the modeled building. In the second stage, it was used to determine the heat transmittance coefficient (U Value) of the existing building components. In the third stage, it was used to calculate the U values of the proposed building components. In the fourth and final stage, it was used for energy consumption analysis, thermal comfort analysis (PMV value) and carbon emission analysis of the building according to the existing and proposed building components.

Calibration

Calibration is performed to test the accuracy of energy models. The most used strategies for calibrating energy simulations of buildings are Dry Bulb Temperature of indoor spaces, air temperature, electricity bills and energy consumed for heating (Chong et al., 2021: 17). For calibration, first the real data of the building is obtained. The same data is then analyzed in a simulation program. In many studies, Coefficient of Variation of the Root Mean Square Error [CV(RMSE)], Mean Bias Error (MBE) or a combination of both is used (Chong et al., 2021; Royapoor & Roskilly, 2015; Şahin et al., 2015). If the results of these data are in accordance with ASHRAE Guideline-14 “Measurement of Energy Demand Savings”, the calibration is considered successful. According to ASHRAE Guideline 14, if the calibration is calculated according to monthly criteria, the MBE value is expected to be within ±5% and the CV(RMSE) value is expected not to exceed 15%. If calculated according to hourly data criteria, the MBE value is expected to be within ±10% and the CV(RMSE) value is expected not to exceed 30%. (ASHRAE, 2002). If calibration is not achieved, the parameter causing the error is determined and necessary adjustments are made. This process continues until calibration is achieved.

$$\mathrm{CV(RMSE)}=\frac{\sqrt{\sum_{i=1}^{ni}\frac{(Mi-Si)^2}{Ni}}}{\frac{1}{Ni}\sum_{i=1}^{Ni} Mi} \qquad \text{Eqs 1.}$$

$$\mathrm{MBE}=\frac{\sum_{i=1}^{Ni}(Mi-Si)}{\sum_{i=1}^{Ni} Mi} \qquad \text{Eqs 2.}$$

Mi and Si are measured in hourly values and simulated hourly values, respectively. Ni, the number of adjustable model parameters (Royapoor & Roskilly, 2015: 113). In this study, indoor dry bulb temperature and outdoor air temperature data were used for calibration purposes. Data recorded with Micro Lite USB Data Logger 5016 was used for the calibration of dry bulb temperature. Hourly averages of measurements taken every 15 minutes were used. The outside air temperature data to be used for calibration was obtained from the closest station to the study area, Turkish State Meteorological Service 15th Regional Directorate, Yenişehir/Eşref Bitlis Heliport/18166. CV(RMSE) and MBE values were determined and evaluated depending on the hourly criteria for the calibration of the measured real data and simulation data.

Thermal Comfort

In the Organisation for Economic Co-operation and Development (OECD) countries, students spend an average of 7634 hours in schools (Organisation for Economic Co-operation and Development, 2023). Inappropriate thermal comfort of school interiors directly affects the level of learning (Pies et al., 2020). Energy retrofitting of educational buildings directly affects indoor thermal comfort (Jerominko & Cichowicz, 2025). Thermal comfort refers to users’ satisfaction with the thermal environment (Zhang et al., 2020). Thermal comfort limitations help to determine the air conditioning of buildings (Taleghani et al., 2013). In this study, Predicted Mean Vote (PMV) and Predicted Percentage of Dissatisfied (PPD) indices were used as thermal comfort limitations (Park et al., 2025). PMV within the ±3 range represents how people perceive the thermal environment. PPD, on the other hand, indicates the percentage of people dissatisfied with the thermal comfort of the environment (ASHRAE, 2017; Wei et al., 2024). Air temperature, mean radiant temperature, air velocity, relative humidity, metabolic rate and clo values are used to calculate PMV values. PPD value is calculated with the formula based on the PMV value (Eqs 3) (ASHRAE, 2017; Zhang et al., 2020).

$$\mathrm{PPD}=100-95e\ (-0.03353\mathrm{PMV}4-0.2179\mathrm{PMV}2) \qquad \text{Eqs 3.}$$

According to ASHRAE Standard 55, the PMV value should be ±0.5 and the PPD index should be below 10% in a comfortable environment. The further away from this value range, the lower the level of satisfaction and thermal comfort (ASHRAE, 2017; Park et al., 2025). In this study, PMV values were simulated daily through DesignBuilder software-Fanger (PMV) output. PPD values were calculated by processing PMV values in Excel program (Eq 3).

Carbon Emissions

In the study, carbon emissions are defined as operational carbon and embodied carbon. CO2 emissions were simulated in DesignBuilder software using Life Cycle Assessment (LCA) data. LCA is a tool that can assess CO2 and other greenhouse gas emissions over the lifetime of a building (Angrisano et al., 2021; Jaemoon et al., 2023). Operational Carbon emissions are usually directly related to fuel type and fuel quantity. Operational carbon emissions are usually directly related to fuel type and fuel quantity. It is the amount of carbon emissions resulting from the energy expended to provide heating, cooling and lighting, etc. Embodied carbon emission is the expression in kg of the amount of carbon emitted during the production, transportation, construction, etc. of building materials (Ibn-Mohammed et al., 2013: 234).

FINDINGS

Analyses and evaluations were completed in three stages. In the first stage, calibration was performed. In the second stage, the U values of the existing building components and the proposed building components were determined. Scenarios were created according to the proposed building components. In this context, Package 1: Original wall + 9cm rock wool + paint + plaster, Package 2: Window replacement: 6mm + 13mm argon + 6mm, Package 3: Attic floor insulation: 13cm rock wool. In the third stage, the effects of the proposed packages on energy consumption, carbon emission and thermal comfort have been analyzed.

Calibration

In the first stage of calibration, simulations and field measurements were conducted for indoor dry-bulb temperature data from 27.05.2025 at 18.00 to 30.05.2025 at 16.00. It was determined that the temperature measurements and simulations for nine different locations were generally parallel (Figure 6).

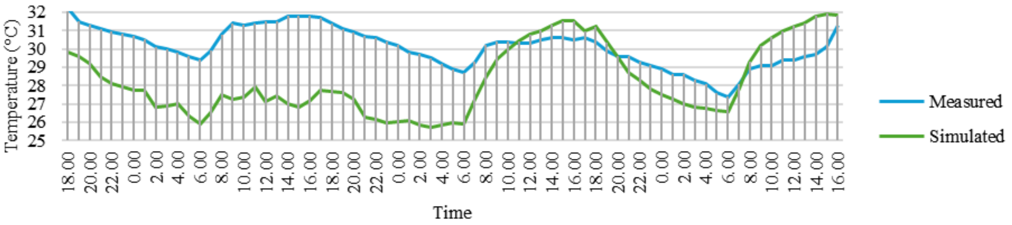

Figure 6. Comparison of temperature data in simulations and measurements (Class 1-04)

MBE and CV(RMSE) values were determined for the calibration evaluations of nine spaces. It was determined that the MBE and CV values in all nine spaces were in accordance with ASHRAE-Guideline 14 (Table 3).

Table 3. Errors for calibration of the model for each space

Metrics	Space									ASHRAE Guideline -14 Limit
	Z-06	Z-07	Z-10	1-01	1-02	1-03	1-04	1-05	1-06	
CV(RMSE) (%)	9.39	7.45	7.5	10.86	9.14	7,97	9.10	9.12	5.62	30
MBE (%)	6.52	0.48	2.28	9.16	5.80	3.58	6.06	8.36	-1.10	±10

In the second stage of the calibration, real outside air temperature data and simulated outside air temperature data were calibrated. In this context, the CV(RMSE) value was determined to be 21.34% and the MBE value to be 9.47% according to the hourly data criteria. The results of the two-stage analysis show that the simulation is calibrated.

Building components

U-values for wall, attic floor, and window (frame + glass) components were determined using DesignBuilder software for both existing and proposed materials. The existing and proposed building components were evaluated by comparing them with the minimum U-values specified for the 4th climate zone in TS 825. Diyarbakır Central district, where the study area is located, is in the 4th climate zone according to TS:825 standards (Turkish Standards Institute, 2024).

Wall: The interior and exterior surfaces of the school walls are basalt stone walls covered with plaster and paint. The walls consist of three layers, stone filling in the middle and basalt stone blocks on the inner and outer surfaces. The U-value of the existing wall is 0.983 W/m²K (Table 4).

Table 4. U-values of base case and proposed wall

Component detail		U value (W/m²K)
Base Case	*Out*-Plaster + paint (1cm) + basalt masonry block (20cm) +gravel (20cm) + basalt masonry block (20cm) +plaster + paint (1cm)-*In*	0.983
Proposed	*Out*-Original wall + rock woll (9cm) +plaster + paint (1cm)-*In*	0.266
TS 285 U value (W/m²K): 0.35		

In Package 1, 9cm thick rock wool insulation material and plaster + paint was added to the inner surface of the original external wall. Rock wool is preferred because it is a natural and recyclable material with low conductivity (λh=0,033), resistant to moisture and fire (Danaci & Akin, 2022). No intervention was made to the outer surface of the external walls of the building. In this context, the U value of the proposed wall was determined as 0.266W/m²K. This value is in accordance with TS 825 4th climate zone wall components U value.

Window: The existing building uses 6 mm transparent single glazed windows with wooden frames with 6 divisions, 1 sash of which can be opened. The U-value of the existing window glasses was determined as 5,778 W/m²K. This value is well above TS 825 standards (Table 6).

Table 6. U-values of base case and proposed window

Component detail		U value (W/m²K)
Base Case	Painted wooden frame + 6mm Clr single glass	4.5
Proposed	Painted wooden frame + Argon-filled Low-E coated double glazing (6mm+13mm+6mm)	1.698
TS 285 U value (W/m²K): 1.8		

The window frames were renewed with the same material and number of divisions. It was proposed to replace the glass with 13mm argon filled Low e (e=2) coated glass (Package 2). In this context, it was determined that the glasses with a U value of 1,698 W/m²K follow TS 825 standards.

Cold roof-Attic floor: The attic of the existing building is not used. In this context, no intervention has been made to the sloping roof. The roof insulation is 8 cm thick glass wool and is laid on the attic floor. The cold roof U value of the existing building is determined as 0.43 W/m²K (Table 5).

Table 5. U-values of base case and proposed attic floor

Component detail		U value (W/m²K)
Base Case	Plaster+paint (2cm) +Reinforced concrete (15cm) + glass woll (8cm)	0.43
Proposed	Plaster+paint (2cm) +Reinforced concrete (15cm) + rock woll (13cm)	0.234
TS 285 U value (W/m²K): 0.25		

To reduce the U value of the attic floor, 13cm thick rock wool is recommended to be laid on the attic floor. Insulation thickness complies with TS 825 standards. No intervention other than insulation material is recommended. In this context, it can be said that the Cold roof U value of 0,23W/m²K is in accordance with TS 825 standards.

Impact of Envelope Retrofitting Strategies on Annual Energy Savings

In the first stage, the heating energy consumption of the existing building was analyzed. In this context, it was determined that the total annual energy consumption was 23252kWh (Figure 7).

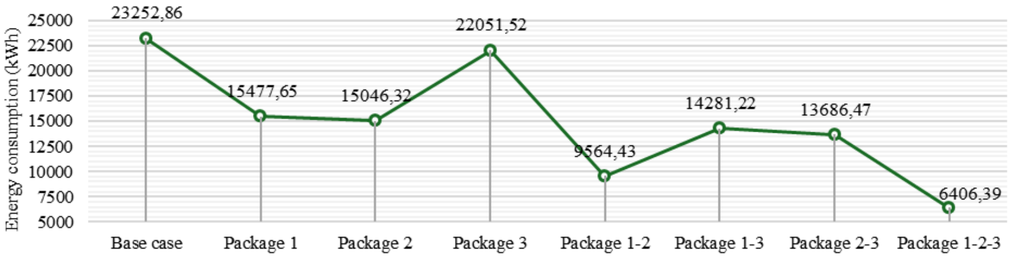

Figure 7. Impact of scenarios on energy consumption

In the second stage, the effect of the proposed scenarios on the energy requirement for heating purposes was analyzed. Package 1, the annual energy demand for heating is found to be 15477 kWh. This shows that the energy demand for heating purposes decreased by 33.43%. When the recommendations within the scope of Package 2 are analyzed, it is determined that the annual energy demand for heating purposes is 15046 kWh. In this context, it can be said that the use of argon-filled low-e double glazing can reduce energy demand by 35.29%. In Package 3, it is determined that the energy demand for heating purposes is 22051 kWh because of the proposal to replace the attic insulation. This shows that only by changing the type and thickness of the attic insulation, can the energy demand be reduced by 1201kWh per year. The combination of packages 1 and 2 resulted in a reduction of the annual energy demand to 9564 kWh. This result shows that the energy demand is reduced by 58.95%. As a result of the combination of Package 1 and 3, the energy demand was 14281 kWh. This shows that the annual heating energy demand will decrease by 38.56%. It is determined that the combination of Packages 2 and 3 will result in an energy demand of 13686 kWh. In this context, it can be said that the energy demand for heating purposes will decrease by 41.13%. In the package 1-2-3 combination proposal, energy demand for heating purposes is determined as 6406 kWh. It shows that 72.43% energy conservation will be achieved because of the implementation of Package 1-2-3 combination. It is also clear that this combination is the most effective method. These results show that a total of 160150kWh energy savings will be achieved in 25 years within the scope of the European Green Deal 2050.

Impact of Envelope Retrofitting Strategies on Thermal Comfort

The analysis revealed that, in the building's current state, thermal comfort conditions (with PMV values within ±0.5 and PPD values below 10%) were maintained for 157 days per year, accounting for 43.01% of the annual period (Figure 8).

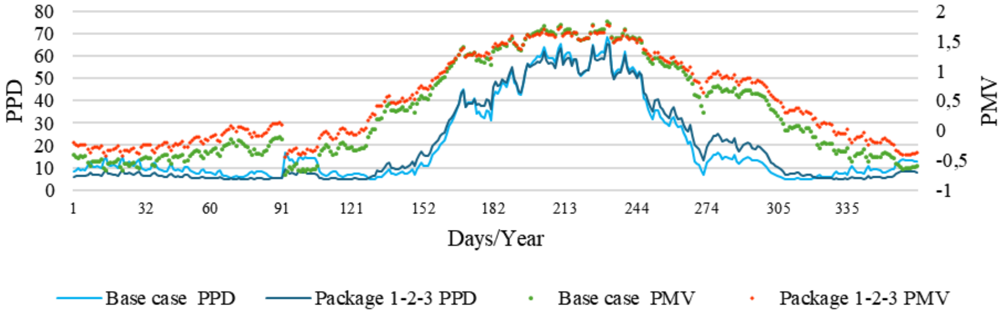

Figure 8. Annual Variation of PMV and PPD Values

In the Package 1-2-3 combination, it was determined that the PMV value remained within the ±0.5 range and the PPD value stayed below 10% for 206 days (56.43% of the year). This indicates an approximate 31% increase in the number of days with thermal comfort because of the implemented recommendations. The days when PMV values are in the ±2 range are usually when school is closed for summer vacation.

Impact of Envelope Retrofitting Strategies on Carbon Emission

It is determined that the annual operational carbon emission of the existing building is 70510kg, while the Package 1-2-3 combination is 63183kg. It can be said that the implementation of Package 1-2-3 will reduce the annual operational carbon emission by 7327 kg. This shows that the operational carbon emission of the building can be reduced by ~10.39% per year (Figure 9).

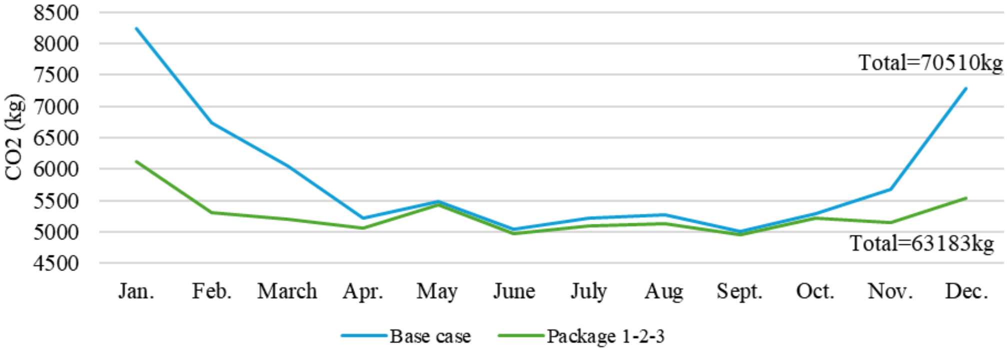

Figure 9. Carbon emission (kg/month)

In the baseline scenario, the embodied carbon emissions of the building is ~431097kg. Under the combination of Package 1-2-3, the embodied carbon emissions of the building is ~445184kg. The difference in embodied carbon between Package 1-2-3 and base case is ~14087 kg. The biggest reason for this increase is the addition of rock wool used in attic floor insulation (Figure 10).

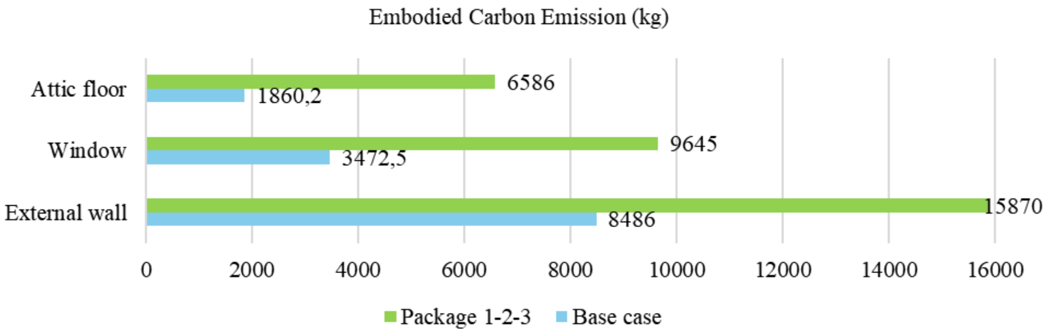

Figure 10. Embodied carbon emission amount of building components

Considering the total life cycle emissions, where operational carbon emissions and total embodied carbon emissions are calculated together, it can be said that the carbon footprint of the building will reach an equivalent level to the base case in about 2 years under the proposed scenario. After 2 years shows that building will become advantageous in terms of carbon emission. Within the scope of the European Green Deal 2050, it can be said that the building will emit 183175kg less carbon emissions in 25 years. This shows that there will be a serious improvement in the carbon footprint of the building (Figure 10).

CONCLUSION

It is very difficult to achieve sustainability only by developing design criteria for new buildings without considering existing buildings. Existing buildings are among the major drivers of energy consumption and carbon emissions. It can be defined as an important solution for sustainability with the right energy retrofits to existing buildings. In recent years, CEN has published encouraging guidelines for energy retrofitting of historic buildings due to their energy consumption, carbon emissions, and inappropriate indoor thermal comfort conditions.

This study focuses on the energy retrofitting of Ziya Gökalp Primary School, which was built as part of a project in Diyarbakır, Türkiye, within the scope of educational reform in the post-Tanzimat period of the Ottoman Empire. Based on real data, the building was simulated using DesignBuilder. First, calibration was performed to ensure accurate data. Then, the proposed scenarios for wall, attic floor and window replacements were compared with the existing condition. All recommendations are in accordance with the EN 16883:2017 guidelines for energy retrofitting of historic buildings, existing literature and national and international laws and regulations for the conservation of historic buildings. Within the scope of these recommendations, it was determined that the most helpful scenario for energy consumption is the Package 1-2-3 combination. It was determined that the Package 1-2-3 combination provides significant advantages in terms of carbon emissions and thermal comfort as well as energy consumption. In this context, it was determined that energy demand decreased by 72.43% and the number of comfortable days increased by 31%. Although there was an increase in embodied carbon emissions, this increase was balanced within two years by a 10.39% reduction in operational carbon emissions. As a result, it can be said that it will provide a significant advantage for carbon emissions. It is thought that the building will provide a significant advantage within the scope of the European Green Deal 2050 by reducing energy consumption by 160150kWh and carbon emissions by 183175kg by 2050. The fact that the existing building was built as a project type suggests that the analyses will yield greater sustainability benefits. Given that the existing building is a type of project, various recommendations for educational buildings in hot, dry climates in the post-Tanzimat period are summarized in Table 7.

Table 7. Evaluation in terms of carbon emissions, energy consumption and thermal comfort

External wall	External wall insulation is a key factor in reducing the heating energy demand. The outer surface of the external wall should not be interfered with as there are decorations. The U-value and carbon emission of the insulation material to be added to the inner surface of the outer wall should be low. Rock wool can be considered as a material suitable for these recommendations. The thickness of the insulation material should be determined by calculating the U-values according to TS 825 and the materials used in the original wall. For the existing building with a U-value of 0.98 W/m²K, a 9 cm thick layer of rock wool, which has a thermal conductivity of λ = 0.033 W/mK, is sufficient.

Window frame	When replacing window frames, it is advisable to choose materials, divisions, and operable sashes that match the building's original or existing condition. In the present study, the material, sash and number of divisions suitable for the existing window frame were preferred.
Window glass replacement	If possible, replacement of a single glass with a low insulation level can be recommended. In case of window glass replacement, DbL Low e(e2=1) Clr 6mm/13mm argon glass can be recommended. Although the embodied carbon emissions are high, the advantage in terms of produced carbon emissions will close this gap in a brief time.
Attic floor	If the attic is not used and there is no insulation material available or if the existing insulation has reached the end of its useful life, it is recommended to use new insulation material. In the existing building, the application of 13cm thick rock wool provided a significant effect as the 8cm thick glass wool, which was worn out in the attic, did not have sufficient U level.

These recommendations for the energy retrofit of historic educational buildings under similar conditions can be considered. However, although their original conditions are like the building within the scope of this study, variables such as differences in material use, location, climatic data, user profiles, and renovations undergone by the buildings should be considered, as they may prevent the proposed scenario from having a similar effect on the existing building.

Author’s Contribution

The author contributed 100% to the study.

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Competing Interests

There is no potential conflict of interest.

Ethics Committee Declaration

This study does not require ethics committee approval.

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Figure References

Figure 2-3: Ergün, Ş. (2024). Diyarbakır Ziya Gökalp Primary School conservation project [Master of Science, Dicle University].

Author's Biography

Ruşen Ergün completed his master's degree in architectural conservation at Eskişehir Technical University and his doctorate in Architecture at Dicle University. He is currently an assistant professor at Dicle University. His work focuses on energy conservation in historic buildings, energy efficiency, sustainable architecture, and related fields.