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Approach Proposal for Energy-Efficient Retrofit of Historic Buildings with Comparative Analysis of EU Research Projects

AB Araştırma Projelerinin Karşılaştırmalı Analizi Doğrultusunda Tarihi Binaların Enerji Etkin İyileştirilmesi için Yaklaşım Önerisi

Elvan Kumtepe[1] İdil Ayçam [2]

ÖZ

Bina sektörü çerçevesinde mevcut yapı stoku önemli enerji tüketim kaynaklarından olması sebebiyle enerji tasarrufu yapılabilme potansiyelinin yüksek olduğu araştırma alanlarındandır. İklim değişikliği ve küresel ısınma etkisi ile enerji tüketiminin giderek artması ve oluşan olumsuz durumların önlenip azaltılması amaçlı birçok mevcut yapı stokuna yönelik çalışmalar yapılmaktadır. Önemli mevcut yapı stoku ana kaynaklarından olan tarihi yapılar için sadece korumanın yetersiz kalması nedeniyle özellikle Avrupa ülkelerinde enerji etkinlik ve verimlilik gibi parametrelerin de müdahale yöntemlerinde koruma ile bütün olarak düşünüldüğü görülmektedir. Müdahaleler için kültürel kimlik değerlerinin korunması ve enerji verimliliğinin sağlanması ana kriterler olarak benimsenmektedir. Bu iki müdahale kriterinin dengede ve bir bütün olarak düşünülmesi ile yapıların gelecek nesiller için kalıcılığı ve sürdürülebilirliği sağlanmaktadır. Bu doğrultuda özellikle Avrupa ülkelerinde yapılan Avrupa Birliği (AB) tarafından desteklenen kapsamlı, büyük ölçekli ve çok uluslu projeler yürütüldüğü görülmektedir. Çalışma ile projelerin detaylı ve sistematik olarak analiz, karşılaştırma ve değerlendirmesi sonucunda elde edilen çıkarımlar doğrultusunda gelecek çalışmalar için yaklaşım ve müdahale model önerisi getirilmiştir. Belirlenen projeler amaç, kapsam, hedef, strateji, içerik ve proje sonucu çıktıları üzerinden detaylı olarak incelenmiştir. Elde edilen veriler doğrultusunda yapılan analiz ile sistematik şekilde çıkarımlar yapılmıştır. Tarihi yapılar için yapılan enerji verimli iyileştirme uygulamalarındaki yaklaşım bilgileri, hedefler, analiz yöntemleri, kullanılan teknoloji ve yazılımlar, aktif-pasif sistem ve yenilenebilir enerji sistemleri, izleme takip sistemleri ve proje sonucunda müdahalenin etkilerinin sürdürülebilir kılınması için elde edilen proje çıktıları verileri gibi veriler üzerinden karşılaştırma ve değerlendirme yapılmıştır. Sonuç olarak tarihi yapıların enerjilerinin verimli bir şekilde iyileştirilmesine yönelik yapılan analiz karşılaştırmaları ve değerlendirmeleri sonucunda elde edilen çıkarımlarla enerji verimliliği iyileştirme müdahale yaklaşımlarına dair kapsamlı bir yaklaşım modeli önerilmiştir. Böylece çalışma ile elde edilen yaklaşım modeli ile tarihi yapılarda enerji verimliliğine dair yapılacak çalışmalarda müdahale modellerinin oluşturulması için rehberlik edecektir.

Anahtar Kelimeler: Tarihi Yapılar, Kültürel Miras Yapıları, Enerji Etkin İyileştirme, İyileştirme Yöntemleri, AB Destekli Projeler

ABSTRACT

Within the framework of the building section, the existing building stock is a research area with a high potential for energy savings, as it is a crucial energy consumption source. Studies are being carried out on many existing building stocks to prevent and reduce the increasing energy consumption and negative situations due to climate change and global warming. It is seen that parameters such as energy efficiency are considered as a whole with conservation in intervention methods, especially in European countries, since only conservation is insufficient for historical buildings, which are one of the primary sources of important existing building stock. Preserving cultural identity values and energy

[1] **Corresponding Author:** Res. Asst., Gazi University, Graduate School of Natural and Applied Sciences, Ankara, Türkiye. elvankumtepe@gazi.edu.tr, ORCID ID: 0000-0003-0652-6188

[2] Prof. Dr., Gazi University, Faculty of Architecture, Department of Architecture, Ankara, Türkiye. iaycam@gazi.edu.tr, ORCID ID: 0000-0001-7170-5436

efficiency are the primary intervention criteria. By considering these two intervention criteria in balance and as a whole, the permanence and sustainability of the buildings for future generations is ensured. In this regard, comprehensive, large-scale, and multinational projects supported by the European Union (EU), especially in European countries, are carried out. In line with the conclusions drawn from the detailed and systematic analysis, comparison, and evaluation of the projects, the study proposed an approach and intervention model for future studies. The determined projects were examined in detail regarding purpose, scope, target, strategy, content, and project outcome outputs. Systematic inferences were made through the analysis in line with the data obtained. Comparisons and evaluations were made on approach information, objectives, analysis methods, technology and software used, active-passive and renewable energy systems, monitoring and tracking systems, and project output data obtained at the project's end to make the intervention's effects sustainable. As a result, a comprehensive approach model for energy-efficient retrofitting intervention approaches has been proposed in line with the conclusions obtained from the analysis, comparison, and evaluations of energy-efficient retrofitting of historic buildings. Thus, the approach model obtained with the study will guide the creation of intervention models for the studies to be carried out on energy-efficient retrofits in historical buildings.

Keywords: Historic Buildings, Cultural Heritage Buildings, Energy-Efficient Retrofitting, Retrofitting Methods, EU Funded Projects

1. INTRODUCTION:

Buildings are responsible for approximately 30% of energy demand and approximately one-third of energy-related CO_2 emissions (Prieto et al., 2017; Shukla & Sharma, 2018). Since a significant portion of energy consumption occurs in the built environment and buildings, many countries need to improve the existing building stock and reduce energy consumption.

Important policies have been developed and continue to be developed for the energy-efficient improvement of the existing building stock. Policies have been developed by the European Commission with the Energy Performance of Buildings Directives (EPBDs) and the Energy Efficiency Directive (EED) to improve energy efficiency and reduce CO_2 emissions for the existing building stock (EPBD, 2002, 2010, 2018; EED, 2012). In line with these policies, strategy targets have been determined for the years 2020, 2030, 2040, and 2050: To make buildings energy efficient, to increase the amount of energy obtained from renewable energy sources, and to reduce greenhouse gas emission values. To make buildings energy efficient, increase the amount of energy obtained from renewable energy sources, and reduce greenhouse gas emission values. The targets by 2020 are to increase energy efficiency by 20%, increase the amount of energy generated by renewable energy sources by 20% and reduce greenhouse gas emissions by 20%. It aims to reduce greenhouse gas emissions by 40% by 2030 and 60% by 2040 (EC, 2010, 2011).

Within the existing building stock, many historic buildings have survived structurally and functionally until today but are waiting to be renovated. Historic buildings are essential to the building stock, especially in Europe. 30-40% of the buildings built before 1945, more than 40% before 1960, and more than 50% before 1970 are of cultural heritage value and should be protected (Economidou et al., 2011; Birchall et al., 2014; Economidou, 2012). Since these buildings were built within the conditions of the period they were built, they may need help adapting to today's conditions. They are not preferred due to disadvantages such as unfavorable climate comfort conditions and high energy consumption. Afterward, they become unusable, abandoned, and fall into disuse. In order to improve the current disadvantageous conditions of the buildings and ensure their sustainability in the future, energy retrofitting interventions should be carried out together with conservation-restoration interventions. With the interventions, it is essential to minimize the negative impact of the buildings on the environment and to maintain their efficient and comfortable use.

Historical buildings add uniqueness to European cities. Distinctive originality keeps tangible and intangible elements such as architectural, cultural, and historical within cultural heritage values. They are, therefore, a living symbol of Europe's rich cultural heritage and diversity. These areas are valuable because they reflect the community's identity and should be protected. An important issue is ensuring the permanence and sustainability of historical buildings in today's conditions. This issue needs to be addressed in a multidimensional manner, covering both the field of conservation and energy.

In today's conditions, where only conservation is insufficient for historical buildings, essential and comprehensive studies are carried out, especially in European countries. In order to ensure the sustainability of historical buildings, many projects supported by the European Union with support programs are carried out. The projects are multidisciplinary and wide-ranging studies that provide direction for future studies. These projects are based on and emphasize that parameters such as energy efficiency, which should be considered only in cases where conservation is insufficient for cultural heritage sites and structures, should be considered as a whole with conservation in intervention methods.

In similar studies in the literature, only a single project has been analyzed. A single project is mainly focused on a single criterion, and the projects are analyzed. Among the studies that take the EFFESUS Project as a scope, some studies deal with the decision support system (Eriksson et al., 2014; Roberti et al., 2018; Egusquiza et al., 2022). A study describes the characterization and data model for buildings (Broström et al., 2013). A study focuses only on window improvements (Misiopecki et al., 2023). There is a study in which reflective coatings for facades and windows were developed (Becherini et al., 2018). There is a study where the values obtained with field studies are revealed (Hermann & Rodwell, 2015). The decision support system is discussed in the studies on the SECHURBA Project (Gigliarelli et al., 2018). In another study, fieldwork was examined in detail (Kikira & Gigliarelli, 2010). For the CO2OLBRICKS Project, an overview of the whole project process was provided (Zagorskas et al., 2013). The data obtained through fieldwork on the Climate for Culture Project were discussed (Rajčić et al., 2018). General information about the project was provided (Huijbregts et al., 2015; Leissner et al., 2015). In studies on the 3ENCULT Project, information on tracking and monitoring systems was provided (Balsamo et al., 2013). General information about the project was given (Troi & Lollini, 2011). Studies have described the decision support system related to the Alpine Atlas Project (Rieser et al., 2021; Troi et al., 2023). A study describing proposals for renewable energy systems was conducted (Lopez et al., 2021). Studies have provided general information about the project (Haas et al., 2021; Herrera-Avellanosa et al., 2024). This study will fill an essential gap in the literature with its originality and scope. A study was conducted in which multiple projects were comprehensively examined, analyzed, and compared, and an approach recommendation model was created. All criteria and approaches for improving energy efficiency in historic buildings have been systematically analyzed and comprehensively compared from the smallest to the largest scale. An approach proposal model was developed in line with the analysis, and comparisons were made. In the approach model proposal, intervention approaches, targets, active-passive and renewable energy systems, analysis methods, technology and software, monitoring and control tracking methods, and output data generated as a result of the project are conveyed in a detailed and systematic manner.

In this regard, within the scope of the study, 6 different projects supported by the European Union, carried out for different focuses, scales, methods, goals, and objectives and with different outputs, are discussed. The projects are multinational, multidisciplinary, and comprehensive. It has been supported by different support programs and is aimed at different building types. There are different approach scales, intervention methods, technologies, and systems.

The study proposes an approach and intervention model to increase energy efficiency by preserving the building stock's cultural heritage value. In this regard, analysis and comparison of European Union-supported projects focusing on the energy-efficient rehabilitation of historical buildings are carried out comprehensively and systematically. A systematic and comprehensive approach model is proposed in line with the inferences obtained from analysis and comparisons. An approach and intervention model proposal are being formulated for interventions to be carried out in future studies.

2. MATERIALS AND METHOD

This study discusses energy efficiency-oriented projects aiming to prevent and mitigate the adverse effects of climate change and global warming on historical buildings in European countries. A 4-stage analysis and comparison evaluation are made, and an approach is proposed due to the data obtained (Figure 1). In the first stage, the area to be analyzed for the study and the projects supported in this area are determined. For this purpose, the historical cities of European countries are determined as the study area due to the density of historical buildings in Europe and the importance given to historical buildings. Six multinational, multidisciplinary, and comprehensive projects implemented in Europe that have made energy efficient in historical buildings at different scales, with different focuses and methods, have been selected. In the second stage, the sub-headings under which the projects will be examined and analyzed are determined. The 6 projects are analyzed in detail under 6 sub-headings: basic approach data, purpose, scope, objective, strategy content, and project outputs. Common and different approaches in the projects are identified. By determining the crucial points in the analysis made in the projects, the points that should be considered in the energy improvement works to be carried out for historical buildings are revealed. In the third stage, a systematic data table on the projects is obtained by making inferences in line with the data obtained from the detailed analysis of the projects under 6 sub-headings. Data tables are created in a detailed and systematic way with basic project data, approaches, objectives, active-passive and renewable systems, analysis methods, technology and software used, monitoring and control tracking methods, and output data generated from the project. Comparisons and evaluations of projects are made through these data tables. In the last stage, a model for energy-efficient improvements of historical buildings is proposed in line with the analysis, comparison, and evaluations. Thus, a vital approach model for improvement approach studies is created by analyzing the project implementations whose results and outputs have been obtained with the comprehensive study.

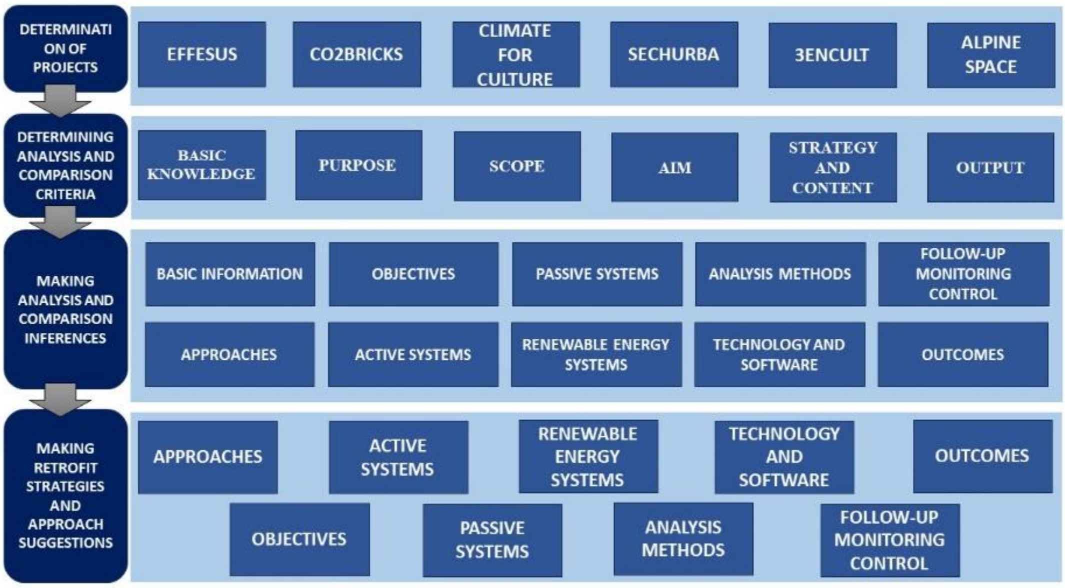


Figure 1. Flow Chart for Retrofit Strategies and Approach Model Suggestion

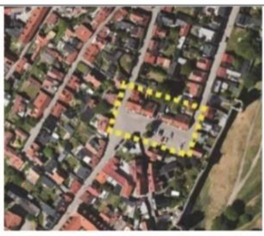
2.1. EFFESUS

"Energy eFFiciency for EU Historic Districts' SUstainability" (EFFESUS) Project was carried out between 2012-2016. It was supported by the "7th Framework Programme", one of the European Union support programs. The project involved 23 partners from 14 countries (Figure 2). The project's main focus was historic districts in Europe, which consist of significant historic buildings built before 1945 (Eriksson et al., 2014).

Figure 2. EFFESUS Project Participants and Project Countries

Scope: In line with the project's scope, most of the settlements identified for the case studies are included in the UNESCO World Heritage Sites list. Case studies in 7 different cities with different building traditions, climatic conditions, and cultural contexts test the applicability and suitability of the project model (EC, 2017a) (Table 1).

Table 1. Regions and Buildings Where Fieldwork was Carried out (Eriksson et al., 2014)

Hanseatic Town of Visby Sweeden			
			

Objective: The project aimed to develop a methodology to prioritize energy efficiency interventions for buildings at the city scale through cost-effective technology solutions that are compatible with heritage values (EC, 2017b). For this purpose, active and passive system solutions were identified to achieve energy efficiency (EC, 2017a).

Goal: The main objective is to develop heritage-compatible technical innovations per the set objectives and create and implement a software-based Decision Support System (Egusquiza et al., 2022). Thus, it will be possible to optimize energy consumption and reduce CO_2 emissions. In this direction, intervention strategies are comprehensively addressed at the regional scale. Urban efficiency was achieved by developing new strategies and analyzing existing information at the regional scale.

Strategy and Content: Three types of intervention packages were implemented regarding project strategies. First, new solutions or solutions adapted from existing solutions were proposed at the urban level. These include district heating solutions, smart energy management systems, photovoltaic and storage systems, and efficient lighting systems. Secondly, new products and systems for application at the building level or new system proposals created with existing products have been produced. These are insulation mortars, radiant reflective coatings, indoor climate control, and secondary window systems. Thirdly, analysis studies were carried out to prepare the building stock (EC, 2017a; Eriksson et al., 2014; Hermann & Rodwell, 2015).

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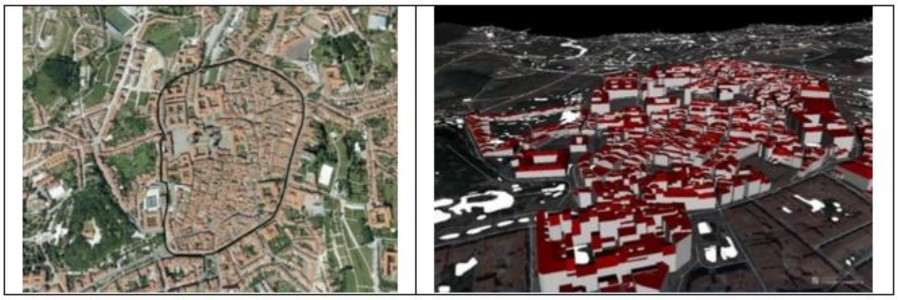
Outputs: A. Data model and solution repository, b. Technology and systems, c. Software tools and methodology were developed using different intervention packages (EFFESUS, 2016).

a. Data Model and Solution Repository: To account for the interactions between the district model and buildings, a scale larger than the scale of individual buildings is needed. The historic district is categorized according to codes, land use, climate, shading effects, and energy supply data. A building typology is created and serves as a representation for applying interventions to the building stock (Broström et al., 2013). Decision-making, management, and analysis steps can be carried out using the created multi-scale data model. The data model is intended to create 3D models semi-automatically using publicly available data (cadastral, LIDAR data, existing 3D models, etc.). Building Information Models (BIM) and Geographic Information Systems (GIS) are linked to create a multi-scale information model based on CityGML (Egusquiza et al., 2014) (Table 2).

Table 2. The Historic District of Santiago De Compostela and Data Model (Egusquiza et al., 2014)



b. Technology and Systems: In historic districts, technologies that provide renewable energy are essential, especially for the retrofitting of buildings (EC, 2017a). Separate solutions for renewable energy integration have been developed at the building and district levels. Solutions for district heating and cooling systems have been introduced. Geographic Information Systems (GIS) were used to create maps and plan and optimize systems (Egusquiza et al., 2014). Interventions for indoor climate and comfort solutions are developed to improve indoor comfort conditions and provide energy efficiency. Indoor ideal target comfort levels are idealized through monitoring and management systems.

Since the building envelope is significant in energy performance, solutions have been produced for elements such as walls, windows, doors, and roofs. When selecting materials or solutions, the preservation of the original materials, the reversibility of the intervention, and the effects of the retrofitting intervention on the heritage value it may create are considered. Within the project's scope, 4 innovative solutions focused on the building envelope were produced. These are aerogel insulation, insulation mortar, radiant reflective coating, and upgraded original windows. Natural lime-based insulation mortar was used on interior and exterior walls. These solutions and materials were tested in laboratories and outdoor test stands and applied in case studies. Bright reflective coatings produced within the project's scope were used for hot climates. With these coatings, high infrared (IR) reflection reduces the amount of solar heat absorbed on the exterior wall or roof and the need for cooling inside the building (Becherini et al., 2018). Several retrofit options have been identified for windows, such as thermal shading and low-emissivity films (Misiopecki et al., 2023) (Table 3). Control and innovative lighting and ventilation systems are proposed (EFFESUS, 2016). Sensors, control, and management systems made the building energy efficient without affecting the heritage value.

Table 3. Installation of Aerogel Fiber Insulation and Natural Lime-Based Insulation Mortar (Rodriguez-Maribona & Grün, 2016), Thermal Shades, and Adhesive Low-Emissivity Films (Misiopecki et al., 2023)

c. Software Tool and Methodology: A software tool, the Decision Support System (DSS), was obtained to assist in decision-making regarding appropriate retrofit measures for historic urban districts (Egusquiza et al., 2014). It was produced as a multi-scale data model consisting of a repository of historic buildings and districts and energy efficiency retrofit solutions (Egusquiza et al., 2022) (Figure 3).

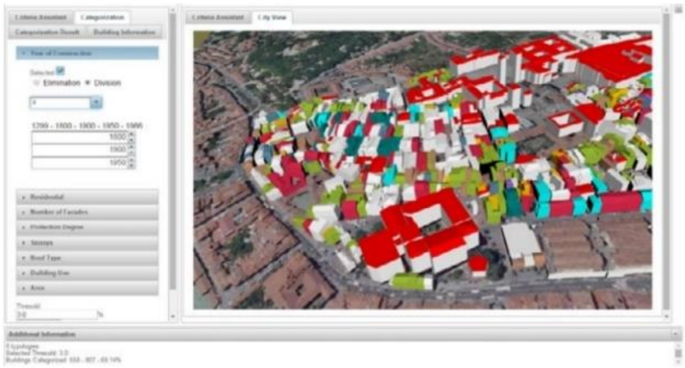


Figure 3. Building Stock and Categorization Tool (Rodriguez-Maribona & Grün, 2016)

2.2. CO2OLBRICKS

The project "Climate Change, Cultural Heritage & Energy Efficient Monuments" (CO2OLBRICKS) was carried out between 2010 and 2013. It was supported by the "Baltic Sea Region Programme" of the European Union (CO2OLBRICKS, 2013a). 18 different multidisciplinary partners from 9 different countries participated (Figure 4). The Project's primary focus is the historic buildings in and around the Baltic Sea, especially those using brick materials.

Figure 4. CO2OLBRICKS Project Participants and Project Countries

Scope: The feasibility and appropriateness of the project model were tested through case studies for 6 cities and 74 buildings in cities in and around the Baltic Sea (Table 4).

Table 4. Buildings where Fieldwork was Carried Out within the Scope of the Project

Elmehuset building, Copenhagen, Danmark	Kavalergården building, Copenhagen, Danmark	Jarrestadt Estate, Hamburg, Germany	Military barracks, Hennala Lahti, Finland
			

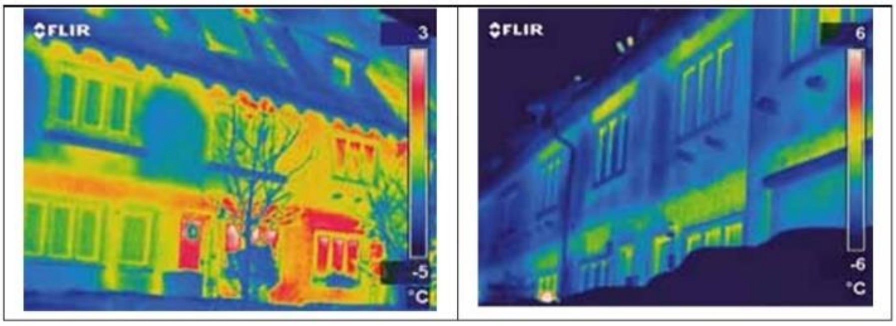
Objective: This Project aims to reduce the energy consumption of historic buildings without harming their cultural value and identity. The main objective is to balance climate protection and heritage conservation. Solutions were sought to reduce CO_2 by combining climate protection needs with technical, administrative, and historically adequate approaches (CO2OLBRICKS, 2013b).

Goal: To preserve the authenticity of historic buildings in the cities around the Baltic Sea. One of the main goals is to optimize energy consumption and find solutions for new potentials for energy production (CO2OLBRICKS, 2012).

Strategy and Content: The project strategies included detailed research, identification of practical examples, development of technical solutions, and pilot projects (CO2OLBRICKS, 2013c). With theory and practice supporting each other, the Project was successfully carried out in line with its aims and objectives. Buildings were intervened at the building element and material levels (CO2OLBRICKS, 2013d). Existing systems were upgraded, and new systems were added to improve energy consumption. In addition, renewable energy systems have been integrated.

Outputs: Intervention approaches for the building envelope have been developed to improve the performance of existing buildings at a lower cost. Measurements were made with thermal cameras to identify problems with the building envelope (Table 5). Energy-efficient solutions were produced by supporting the on-site measurements with the analysis made with Energyplus simulation software (CO2OLBRICKS, 2013e).

Table 5. Thermography of the Building Envelope (Dulnewa et al., 2013)



The Project identified measures for active and passive systems. Significant energy-saving opportunities have been introduced, such as insulation, shading, ventilation and heating systems, and home automation (CO2OLBRICKS, 2013f) (Table 6).

Table 6. Insulation, Wall Heating Systems, Heat Pump Systems, Shading Systems (Rasmussen, 2013)

Internal and limited external insulation was proposed for external walls (Zagorskas et al., 2014). Floor slabs, roofs, attics, and basements were insulated. Windows and doors were retrofitted or replaced (CO2OLBRICKS, 2013d). Breathable insulation materials with optimum values for bricks were evaluated. Glass fiber, glass wool, rock wool, hemp fiber, sheep wool, polyurethane foams, and aerogel insulation materials were preferred (Zagorskas et al., 2013; CO2OLBRICKS, 2013g). Improvement of HVAC (Heating, Ventilation, and Air Conditioning) systems, energy-efficient lighting and electrical equipment, HVAC system automation, and smart control systems were added (CO2OLBRICKS, 2013f). Improvements with radiant heating, heat pump systems, and wall heating systems were proposed (Friese & Worch, 2013; Gerbitz, 2013) (Table 6). A life cycle analysis of each intervention project was carried out. Cost-effectiveness was checked (Zagorskas et al., 2013).

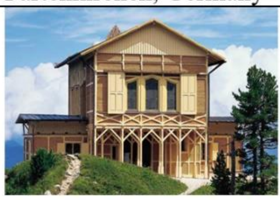
2.3. CLIMATE FOR CULTURE

The “Climate for Culture” project was conducted using an approach between 2009 and 2014. It was supported within the scope of the “7th Framework Programme”, one of the European Union support programs (Fraunhofer, 2014). It is a comprehensive project with the participation of 14 countries and 27 partners (Figure 5). In particular, the project focused on historic buildings in Europe and the Mediterranean (EC, 2019).

Figure 5. Climate for Culture Project Participants and Project Countries

Scope: The applicability and suitability of the project model were tested in the context of more than 100 historic buildings in Europe and the Mediterranean (Table 7). In the database created with the data from the case studies, results were obtained for 4 climate zones and different building types (Leissner et al., 2014).

Table 7. Buildings where Fieldwork was Carried Out within the Scope of the Project

Neuschwanstein Castle, Schwangau, Germany	King's House on Schachen, Garmisch-Partenkirchen, Germany	St. Margaretha church in Roggersdorf, Germany	Skokloster Castle, Sweden
			

Objective: To meet sustainability criteria in future scenarios in different regions of Europe and the Mediterranean region. It also aims to analyze the negative impact of climate change on cultural heritage sites and promote climate change mitigation strategies (EC, 2019).

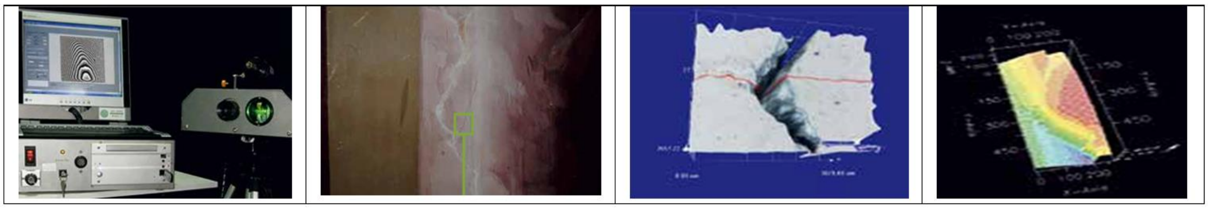
Goal: Upgrade old heating and air circulation systems, develop passive air conditioning for microclimate control, and promote the use of renewable energy (Rajčić, 2018).

Strategy and Context: The damaging impact of climate change on cultural heritage was assessed at an integrated regional scale. Climate change evolution scenarios were combined with whole-building simulation models to identify risks regionally. A more reliable damage assessment was made by combining future time climate data with whole-building simulation models and new damage assessment functions (Leissner, 2015) (Figure 6).

Figure 6. The Climate for Culture Project Methodology (Leissner, 2015)

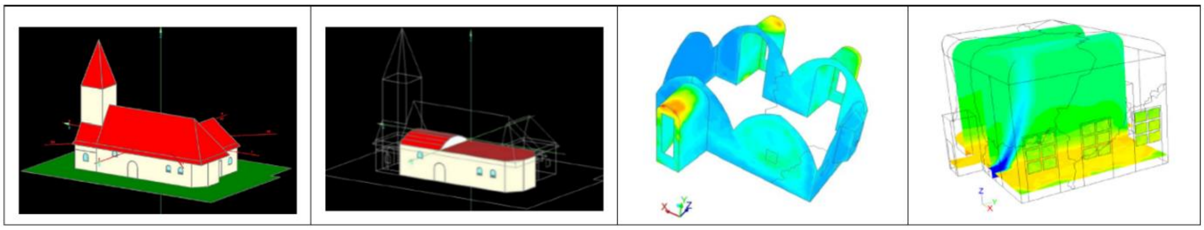
On-site measurements of cultural objects were made non-destructively with DHSPI, Digital Video Microscope System Hirox (3DM), and Free Water Sensors. The measurements were compared with those in the humidity control algorithm software (EC, 2015a) (Table 8).

Table 8. Portable DHSPI System, In-site Wall Examination with DHSPI, 3dm Results, DHSPI Results (Leissner et al., 2014)



The impact of climate change on cultural heritage buildings has been studied through climate modeling and whole-building simulations. In addition, determinations were made by making on-site measurements. Economic impacts were also considered when determining sustainable mitigation/adaptation strategies (Rajčić, 2018) (Table 9).

Tablo 9. St. Barbara's Chapel Simulation Models (Rajčić, 2018) and Holy Cross Chapel Dynamic Models (Leissner, 2015)



Outputs: With the data obtained from the project, a. Analysis and Decision Support System, b. Risk assessment and risk maps, c. Expert decision system (exDSS), d. Database, e. "DigiChart" software for digitizing thermo-hygrograph graphics was created (EC, 2015a; Leissner et al., 2014; Huijbregts et al., 2015).

a. Climate modeling and building simulations were combined to develop a methodology for estimating the impact of historic buildings on their exterior and interior environments and the future energy demand needed for air conditioning.

b. High-resolution climate projections around Europe and the Mediterranean and the impact of climate change in various regions were observed. With these climate projections, risk maps have been created regarding the risks that may arise in the future for historic buildings and their interiors.

c. An expert decision system (exDSS) was created based on the data obtained.

d. 14 work packages were implemented to create climate change scenarios in 4 climate zones for the database. The most at-risk regions in Europe were identified through climate models and climate maps until 2100. Active and passive measures for improvements in buildings were identified.

e. DigiChart software has been developed to keep digital records of buildings' indoor temperature and humidity values.

2.4. SECHURBA

The "Sustainable Energy Communities in Historic URBan Areas" (SECHURBA) project was carried out between 2008-2011. It was supported by the "Intelligent Energy Europe Programme," one of the European Union support programs. 7 countries participated (Kikira & Gigliarelli, 2010) (Figure 7). 30 historic buildings were surveyed and surveyed. The project focused on energy efficiency and renewable energy for buildings in historic cities.

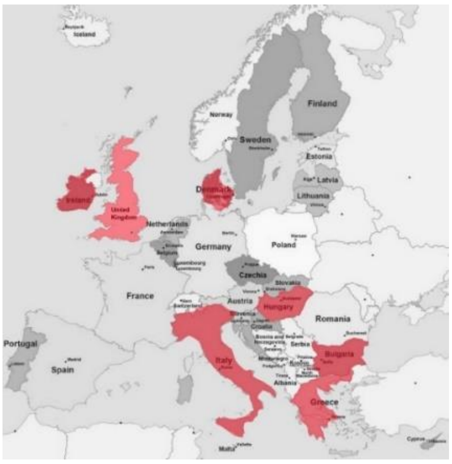


Figure 7. SECHURBA Project Participants and Project Countries

Scope: 30 case studies were conducted on buildings identified as historical heritage in Europe, and energy savings were calculated (Kikira & Gigliarelli, 2010) (Table 10).

Table 10. Buildings where Field Work was Carried Out within the Scope of the Project (URL 1)

Greece Athens, Centre Buildings and Rhodes Theatre	Denmark Copenhagen, City Hall	United Kingdom, Tanners Wine Merchants	United Kingdom, Parade Shopping Centre
			

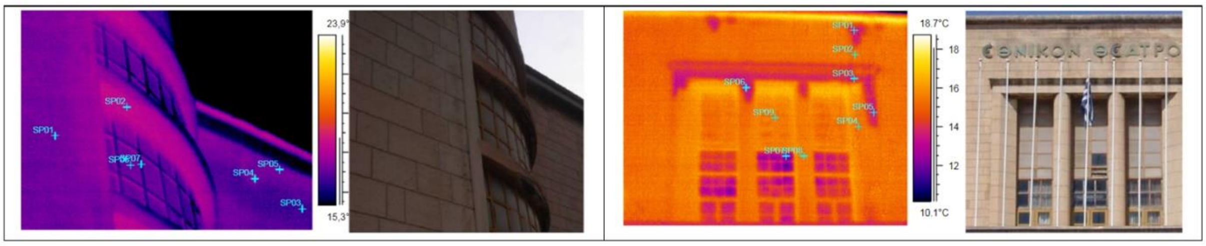
Objective: It is aimed to promote energy efficiency practices and renewable energy systems in historical residences. Energy auditing methods and software have been created to promote sustainable energy interventions. Recommendations have been created to reduce energy demands by at least 40% (Cessari & Gigliarelli, 2012).

Goal: It aims to make historical areas sustainable by reducing carbon emissions to ensure their continuity in modern life. Roadmaps for carbon reduction have been determined (Broström et al., 2014). It also aims to meet energy needs by integrating renewable energy systems (López & Frontini, 2014).

Strategy and Content: Building and field analyses and measurements were carried out to obtain historical building data (Table 11). Typological data and dimensional data were created. Energy usage demands were determined to develop a decision model for energy retrofitting of historical buildings. Determinations have been made for building interventions (insulation coatings, etc.) to reduce demands. Insulation options have been determined for the inner surface of external walls, roof, floor, and unheated areas (Kikira & Gigliarelli, 2010).

Additionally, work was carried out on window repair and replacement. Improvements to HVAC systems were considered. Heating, cooling, and lighting systems have been proposed to improve indoor air quality. Steps such as determining heating and lighting systems have been determined.

Table 11. Thermographic Analysis was Conducted Using Field Studies (Kikira & Gigliarelli, 2010)



Outputs: As a result of the project, a Multi-Criteria Decision Model was obtained. A multi-criteria analysis and evaluation model is created with energy efficiency and determined efficiency solutions (Gigliarelli et al., 2018) (Figure 8).

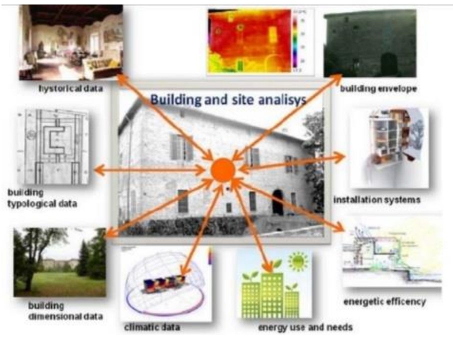


Figure 8. Multi-Criteria Analysis Technique for the Project (Kikira & Gigliarelli, 2010)

A multi-criteria decision-making system has been created with international agreements on conservation, energy efficiency data, environmental compatibility data, and economic data (Cessari & Gigliarelli, 2012). The hierarchical order of the criteria and sub-criteria created for the intervention was examined. Protection according to international protection agreements (46%) receives the highest priority compared to other criteria. Energy efficiency (24%) is the second highest priority. It has the same value as Environmental sustainability (15%) and Economic feasibility (15%) (Gigliarelli et al., 2011). Looking at intervention strategies, the sealing and insulation of the building envelope (external walls, roofs and ground floors, shutters, doors, and windows) have been increased (Kikira & Gigliarelli, 2010). Reducing energy consumption for cooling in summer and heating in winter, improving the hot water system, and improving indoor and outdoor lighting have been achieved (Broström et al., 2014).

2.5. 3ENCULT

The Project titled "Efficient Energy for EU Cultural Heritage" (3ENCULT) was carried out between 2010-2014. It was supported within the scope of the "7th Framework Programme", one of the European Union support programs (3ENCULT, 2014a). It involved 22 partners from 10 countries (Figure 9). The main focus is on the energy efficiency of historic buildings in Europe, especially in the Mediterranean.

Figure 9. 3ENCULT Project Participants and Project Countries

Scope: The applicability and relevance of the Project were tested with 8 case studies for buildings identified as historical heritage in Europe, especially in the Mediterranean (3ENCULT, 2014b) (Table 12).

Table 12. Buildings where Fieldwork was Carried Out within the Scope of the Project (3ENCULT, 2014b)

Palazzo d'Accursio, Bologna (Italy)	Warehouse City, Potsdam (Germany)	Industrial Engineering School, Béjar/ Salamanca (Spain)	Strickbau, Appenzell (Switzerland)
			

Objective: The project's main objective is to ensure the continuity of historical buildings as living spaces and urban sustainability by considering structural conservation and protection of climate comfort conditions as a whole. Interdisciplinary steps have been taken to protect historical buildings and climate in parallel. While taking these steps, conservation elements and energy needs were considered (Roberti et al., 2017).

Goal: The project aims to achieve sustainable urban renovation of European historic buildings through energy-efficient renovation and smart monitoring and control systems. The gap between the protection of historic buildings and climate protection has been filled (3ENCULT, 2014c).

Strategy and Content: In line with the identified goals and objectives, the project steps in the strategy packages created for the project process were determined (Figure 10). Thus, passive and active systems and energy improvement solutions were developed. Due diligence and monitoring tools and systems were developed. Monitoring and control systems were developed for long-term tracking of energy demand, indoor air quality, and occupant comfort. In addition, design and technical solution guidelines have been developed in detail for information (3ENCULT, 2014d).

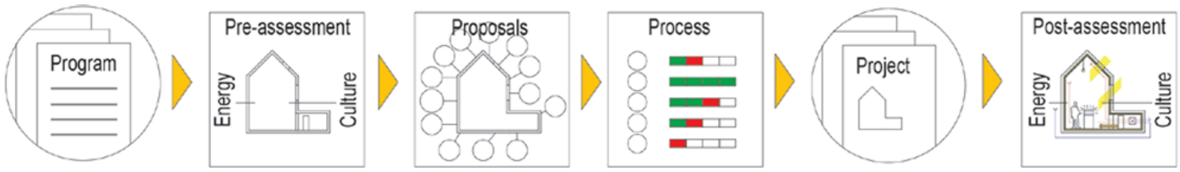
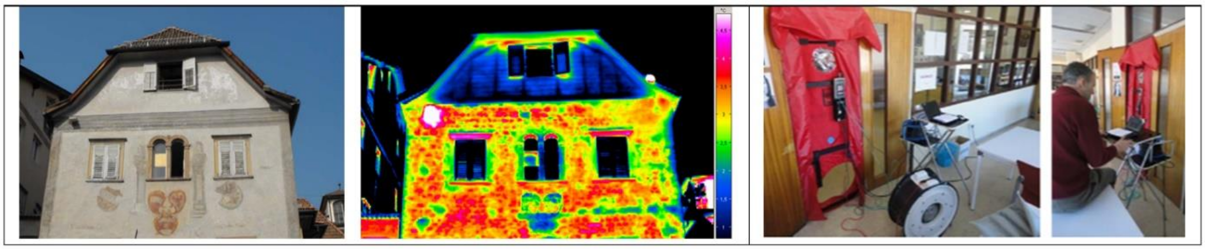


Figure 10. Project Workflow Chart (3NCULT, 2014g)

The Project has been developed, where possible, by non-invasive and utterly reversible diagnostic and monitoring analysis to increase the level of knowledge of the building and to assess its performance through GPR radar tests for masonry stratigraphy; Infrared Thermography (IRT) for structural analysis and moisture assessment; Blower door test; U-value determination; Monitoring trough WSN (EC, 2015b) (Table 13). Solutions and guidelines have been created to integrate solar energy systems from renewable energy systems and PV and RES integration. Intelligent monitoring and control systems and wireless sensor BMS system data have been studied (3ENCULT, 2014e).

Table 13. Infrared Thermography (IRT) (3NCULT, 2014h) and Blower Door Test (3NCULT, 2014i)



Outputs: With all the interventions, data has been obtained to reduce the energy demand in historic buildings to at least 1/4 and at most 1/10. Without ignoring the important point that each historic building is unique, a pool of solutions was created to guide each building (Roberti et al., 2017). The Monument Information System (DIS), a web-based system focused on the needs of conservation, restoration, and energy applications, was used as a digital database. All information documents, images, and catalogs are up-to-date (Figure 11).

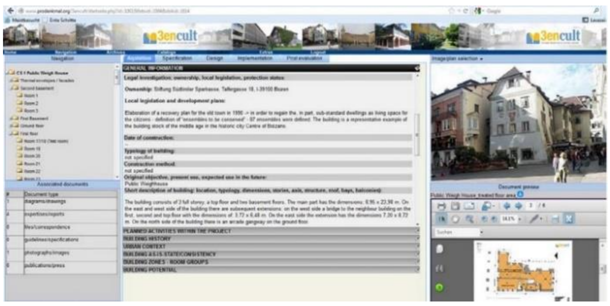


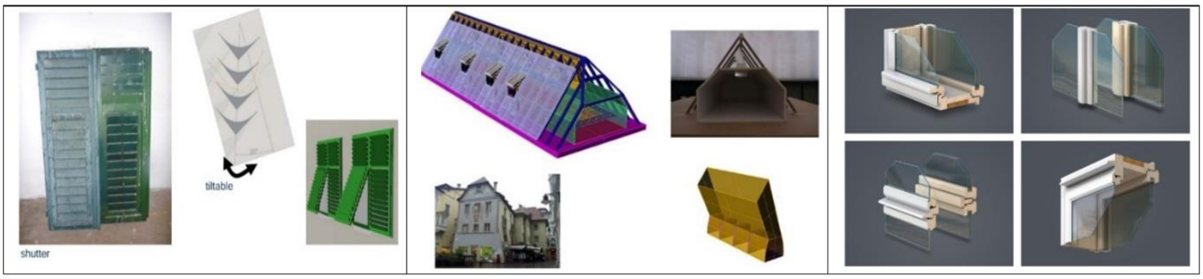
Figure 11. User Interface Database Monument Information System (DIS) (3NCULT, 2014k)

As insulation, breathable internal insulation systems were determined to remove vapor moisture and liquefaction from the walls. Prototypes have been produced and proposed with foam glass and siliceous aerogel panels. Internal insulation boards with an air and vapor-tight layer, capillary active internal insulation with thin plaster on the inner surface, and capillary active internal insulation were used (Table 14).

Table 14. Types of Insulation Used in the Project (3NCULT, 2014l)

Smartwin Historic window solution was produced for the window solution proposal. It is a wooden framed window system with 3 glass layers on the outside and 1 glass layer on the inside. Wood fiber insulation is applied on the outer layer of the frame. Daylight and lighting control is provided by integrated daylighting systems, roof openings, reorientation of window shutters, and films applied to the windows (3ENCULT, 2014f) (Table 15).

Table 15. Window Shutters, Roof Opening Systems, and Smartwin Historic Window Solution (3NCULT, 2014m)



Heating-cooling consumptions and renovation costs are minimized with the genetic optimization algorithm developed for the Project to find the best solutions (Troi & Bastian, 2015). A solar translucent double-glazed insulated PV window was used. A semi-transparent solar panel with thermal insulation and transparency features was designed for facades through which ambient light can pass (3ENCULT, 2014f).

2.6. ALPINE SPACE

The Alpine Space project was carried out between 2018 and 2021. It was supported by the European Regional Development Fund (ERDF), one of the European Union support programs (Alpine Space, 2021). Austria coordinated the project with 8 partners in 12 countries (Figure 12). The main focus is on historic buildings and settlements in Europe, emphasizing historic buildings in the Alpine region (Troi et al., 2023).

Figure 12. Alpine Space Project Participants and Project Countries

Scope: The feasibility and suitability of the project model are being tested with more than 70 historic buildings in Europe, focusing on historic buildings in the Alpine region (Hiberatlas, 2021) (Table 16).

Table 16. Buildings where Fieldwork was Carried Out within the Scope of the Project (Hiberatlas, 2021)

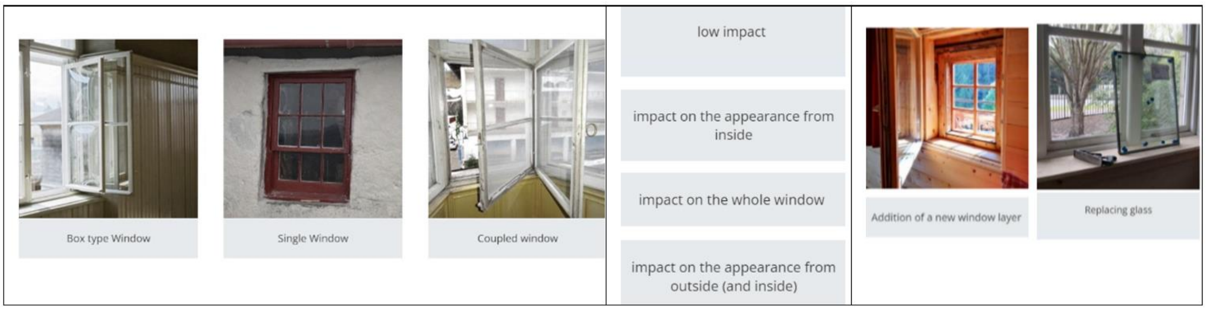
The Alte Schäfflerei at Benediktbeuern Monastery, Germany	Farm house Huber, Rodeneck, İtaly	Trikåfabriken, Stockholm, Sweden	Freihof Sulz, Austria
			

Objective: To create alternatives for the sustainable development of historic buildings. The aim is to reduce the ecological footprint and carbon emissions and increase the energy efficiency of the historic building stock. Methodologies and tools for implementing optimal sustainable regional development policies and renovation strategies (Haas et al., 2021). In-depth documentation provided extensive information for building owners, practitioners, and decision-makers on building renovations, possible technical solutions, and the related decision process (Herrera-Avellanosa et al., 2024).

Goal: The project aims to sustainably improve the energy performance values of historic buildings. Improvements are made with new technologies and suggestions while preserving the values of historical buildings (Troi et al., 2023).

Strategy and Content: Improvement proposals were identified with active-passive and renewable energy systems. These improvements were tested for applicability and efficiency in case studies, and results were obtained (Rieser et al., 2021). Appropriate recommendations for doors and windows and solutions for air tightness were presented for passive systems. In the interventions for windows, window types in the case studies were determined. Intervention impact levels suitable for window types were created. These impact levels determined the types of interventions to be made (Table 17).

Table 17. Window Types, Intervention Impact Levels, and Remediation Options (Hibertool, 2021a)



For walls, the wall types in the case studies were determined. Improvement solution strategies tailored to wall types have been created. The types of interventions to be made by the impact levels of the solution strategies have been determined (Table 18).

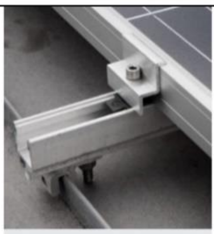
Table 18. Wall Types and Retrofit Options (Hibertool, 2021b; Rieser et al., 2021)

Different materials, solutions, and applications have been determined to determine and improve the airtightness of buildings (Table 19).

Table 19. Applications for Airtightness (Hibertool, 2021c)

Solar energy has been preferred for renewable energy production. Renewable energy systems integrated or connected to the roof, integrated or connected to the facade, or independent have been proposed (López et al., 2021) (Table 20).

Table 20. Solar Systems are Used for Renewable Energy Production (Hibertool, 2021d).

				
Roof integrated renewables	Renewables attached to the roof	Facade integrated renewables	Renewables attached to the facade	Free standing renewables & renewables integrated into the landscape

Outputs: The most critical outputs obtained by the project to ensure energy efficiency in historical buildings are Tool and Atlas tools. With Tool, a tool has been created to determine solutions for historical buildings' windows, walls, ventilation, heating, and solar energy. An online database containing all data on the buildings improved within the project's scope was created with the Atlas tool. All buildings' old and new architectural data, improvement intervention data, efficiency performance, and cost values are given (Troi et al., 2023; Haas et al., 2021).

3. FINDINGS

All projects have proposed critical systems, materials, and approaches to the study area and provided comprehensive project outputs. All project data provide essential and comprehensive bases for future approaches in the field. For this reason, the analyses and the data obtained are compared and evaluated in this section. The evaluations are tabulated comprehensively and systematically, and inferences are made regarding intervention approaches.

3.1. BASIC INFORMATION

As the projects are comprehensive and multinational, they have been implemented for at least 3 years and up to 5 years. Climate for Culture has the longest duration (2009-2014) and the highest number of participating partners (27). The most recent project with the highest budget is Alpine Space. The most recent project is Alpine Space, which was completed in 2021. Regarding support programs, the “7th Framework Programme” offers the most support for historic buildings and energy efficiency.

According to the participating countries of the projects, Germany and Italy are the most participating countries in 5 projects. According to the participating countries of the projects, Germany and Italy are the most participating countries in 5 projects. In both countries, cultural heritage structures are still very numerous today. In addition, these countries are more involved in the projects because they attach great importance to cultural heritage structures. Another situation can be said that the search for solutions is high due to climatic conditions. Cold climatic conditions, precipitation, and humidity factors are essential reasons (Table 21).

Table 21. Basic Information Regarding Projects

BASIC INFORMATION							
	NAME OF PROJECT ABBREVIATION	YEAR	BUDGET	NUMBER OF PARTICIPANTS	NUMBER OF PARTICIPANT COUNTRIES	PARTICIPATING COUNTRIES	FUNDING PROGRAMME
EFFESUS	Energy eFFiciency for EU Historic Districts' SUstainability	2012-2016	6.786.903,26 €	23	14	Spain, Germany, Italy, Greece, Norway, Turkey, Sweden, Ireland, United Kingdom, Netherlands, Hungary, France, Portugal	EU- 7th Framework Programme (FP7)
CO2OLBRICKS	Climate Change, Cultural Heritage & Energy Efficient Monuments	2010-2013	4.300.000 €	18	9	Denmark, Germany, Sweden, Finland, Estonia, Latvia, Lithuania, Poland, Belarus, Russian Federation	EU- Baltic Sea Region Programme
CLIMATE FOR CULTURE	Climate For Culture	2009-2014	6.556.646 €	27	14	Czech Republic, Italy, Croatia, Greece, Netherlands, Slovenia, Sweden, Poland, Austria, Spain, Egypt, England, Germany, Romania	EU- 7th Framework Programme (FP7)
SECHURBA	Sustainable Energy Communities in Historic URBan Areas	2008-2011	-	13	7	United Kingdom, Bulgaria, Denmark, Greece, Hungary, Ireland, Italy	EU-Intelligent Energy Europe Programme
3ENCULT	Efficient ENergy for EU Cultural Heritage	2010-2014	6.704.955,74 €	22	10	Germany, Austria, Belgium, United Kingdom, Czech Republic, Denmark, France, Netherlands, Spain, Italy	EU- 7th Framework Programme (FP7)
ALPINE SPACE	Alpine Space	2018-2021	116.635.466,00 €	12	8	Austria, Belgium, Denmark, France, Germany, Italy, Slovenia, Spain, Sweden, United Kingdom, Switzerland, Turkey	European Regional Development Fund (ERDF)

3.2. APPROACHES

When evaluated according to the types of buildings focused on, EFFESUS, 3ENCULT, and Alpine Space projects addressed all historical buildings regardless of type. On the other hand, climate for Culture and SECHURBA projects stated that they focused on many building types separately. CO2OLBRICKS, on the other hand, stated that they examined all buildings with brick as a building material with a different approach. When the projects are evaluated according to their foci, it is seen that all of them focus on historical buildings in Europe. In addition, customized foci are also specified in the projects.

When the projects are evaluated according to their focus, it is seen that all of them focus on historical buildings in Europe. In addition, privatized foci are also mentioned in the projects. The EFFESUS project is limited to historical buildings before 1945 and by year. The CO2OLBRICKS project focused on buildings in and around the Baltic Sea. On the other hand, Alpine Space prioritized historical buildings in the Alps Region. The Climate for Culture and 3ENCULT projects also focus on buildings in a specific region, especially historic buildings in the Mediterranean.

Regarding the focal approach scales of the projects, we see two different types of scales: building scale and district scale. In such improvement projects, more efficient results are obtained, and more effective results are achieved than those achieved by regional-scale approaches. The main objectives can be achieved more effectively by implementing the decisions that must be taken comprehensively. The results obtained from individual buildings may have a smaller impact value. Considering the projects, it is stated that buildings are handled at the regional scale in EFFESUS, CO2OLBRICKS, and Climate for Culture projects. Thus, they have proposed solutions for holistic improvements at the city and regional scale. Other projects have created improvement models by addressing buildings at the building scale. Although other projects also addressed buildings at the building scale, they tried to provide a majority by addressing too many buildings individually. They also stated that they created a comprehensive database with all buildings (Table 22).

Table 22. Approaches Information Regarding Projects

APPROACHES					
	BUILDING TYPES	FOCUS OF PROJECT	PURPOSE	SCALE	AMOUNT
EFFESUS	All historical buildings	Historical buildings built before 1945	Developing technologies and systems to improve the energy efficiency of historical urban districts.	City, District, Building	7 Cities
CO2OLBRICKS	All building types with brick materials	Historical buildings in and around the Baltic Sea	Reducing energy consumption without damaging the cultural values and identities of historical buildings.	District, Building	6 Districts 74 Buildings
CLIMATE FOR CULTURE	Castle, Church, Monastery, Museum, Palace, Residences	Historical buildings in Europe and the Mediterranean	Reducing the negative effects of climate change for cultural heritage buildings	District	More than 100 Buildings
SECHURBA	Art Galleries Churches Office Buildings Residences	Historical buildings	Reducing energy demands and reducing carbon emissions in residences in historic districts	Building	30 Buildings
3ENCULT	All historical buildings	Historical buildings in Europe, especially in the Mediterranean	Making historical buildings energy efficient	Building	8 Buildings
ALPINE SPACE	All historical buildings	Historical buildings in Alpines	Reducing the ecological footprint and carbon emissions and increasing the energy efficiency of the historic building stock	Building	More than 70 Buildings

3.3. OBJECTIVES

Although the primary goal of all projects is to improve historic buildings energy-efficiently, different points are emphasized in some projects. In all projects, interventions are made, and improvement solutions are offered on energy efficiency, cost efficiency, and indoor thermal comfort. Apart from this, the Climate for Culture project focused more on climate change impacts and the mitigation of climate change impacts for cultural heritage buildings in future scenarios. In addition, no data shows that detailed solutions were produced on the issue of CO_2 emission reduction in this project. Another differentiated project is the CO2OLBRICKS project. This project focused on the most targets. Unlike the other projects, life cycle assessment (LCA) was emphasized. Environmental impact values covering the whole life cycle of the buildings were considered, and suggestions for improvement were created (Table 23).

Table 23. Objectives Information Regarding Projects

OBJECTIVES							
	HERITAGE VALUE	ENERGY EFFICIENCY	THERMAL COMFORT	CLIMATE PROTECTION	LIFE CYCLE ASSESSMENT (LCA)	CO2 EMISSION REDUCTION	COST EFFECTIVE
EFFESUS	✓	✓	✓	—	—	✓	✓
CO2OLBRICKS	✓	✓	✓	—	✓	✓	✓
CLIMATE FOR CULTURE	✓	✓	✓	✓	—	—	✓
SECHURBA	✓	✓	✓	—	—	✓	✓
3ENCULT	✓	✓	✓	—	—	✓	✓
ALPINE SPACE	✓	✓	✓	—	—	✓	✓

3.4. PASSIVE SYSTEMS

Improvement methods for building envelopes play an important role. It was checked whether interventions were made to the wall, floor, door, window, and roof elements. Significant results were obtained primarily for the interventions made to the walls and improvements. Thus, improvements were made to the structural elements of the wall in all of the projects. Interventions are known to be made to the windows in all projects except the Climate for Culture project. Looking at the applications made in the Alpine Space project, it is seen that intervention decisions were taken for walls, floors, roofs, and windows. However, within the project's scope, interventions on walls and windows were developed in detail. EFFESUS, CO2OLBRICKS, and SECHURBA are projects where interventions were made to the floor, roof, door, and walls. Especially in the EFFESUS Project, new material and system solutions were produced for the interventions made in the building envelope. Thus, essential solutions and material suggestions have been made for the building envelope for future projects within the scope (Table 24).

Table 24. Passive System Information Regarding Projects

PASSIVE SYSTEMS					
	WALL	FLOOR	ROOF	WINDOW	DOOR
EFFESUS	✓	✓	✓	✓	✓
CO2OLBRICKS	✓	✓	✓	✓	✓
CLIMATE FOR CULTURE	✓	—	—	—	—
SECHURBA	✓	✓	✓	✓	✓
3ENCULT	✓	—	—	✓	—
ALPINE SPACE	✓	✓	✓	✓	—

3.5. ACTIVE SYSTEMS

Active systems were also utilized within the scope of improvement in the projects. It was observed that additions and improvements were made to the heating, cooling, ventilation, and lighting systems. Only Climate for Culture and Alpine Space projects do not mention lighting improvements. All active system improvements were implemented in all projects except for these projects (Table 25).

Table 25. Active System Information Regarding Projects

ACTIVE SYSTEMS				
	HEATING	COOLING	VENTILATION	LIGHTING
EFFESUS	✓	✓	✓	✓
CO2OLBRICKS	✓	✓	✓	✓
CLIMATE FOR CULTURE	✓	✓	✓	—
SECHURBA	✓	✓	✓	✓
3ENCULT	✓	✓	✓	✓
ALPINE SPACE	✓	✓	✓	—

3.6. RENEWABLE ENERGY SYSTEMS

It has been observed that renewable energy sources are utilized to reduce and meet the energy needs of buildings. It is seen that renewable energy sources are utilized to reduce the energy needs of the buildings and to meet the needs. The EFFESUS project utilizes solar, wind, biomass, near-surface geothermal, and deep geothermal energy. The Alpine Space Project utilizes solar, biomass, near-surface geothermal, and deep geothermal energy. However, only solar energy was emphasized in detail in the project. It was also observed that solar energy was utilized in the SECHURBA and 3ENCULT projects. In particular, it was observed that the use of PV was widespread in these projects. The Climate for Culture project has no suggestions for renewable energy systems (Table 26).

Table 26. Renewable Energy Systems Information Regarding Projects

RENEWABLE ENERGY SYSTEMS					
	SUN	WIND	BIOMASS	NEAR-SURFACE GEOTHERMAL ENERGY	DEEP GEOTHERMAL ENERGY
EFFESUS	✓	✓	✓	✓	✓
CO2OLBRICKS	—	—	—	—	—
CLIMATE FOR CULTURE	—	—	—	—	—
SECHURBA	✓	—	—	—	—
3ENCULT	✓	—	—	—	—
ALPINE SPACE	✓	—	—	—	—

3.7. ANALYSIS METHODS

In order to determine the necessary intervention methods and improvement proposals, some analysis methods were applied to the structures. On-site measurement and simulation studies were applied in all projects. Experiments on building materials were conducted in EFFESUS, Climate for Culture, and 3ENCULT projects. Experiments were conducted on the materials in the case studies, new building material proposals, and building material improvements (Table 27).

Table 27. Analysis Methods Information Regarding Projects

ANALYSIS METHODS			
	ON-SITE MEASUREMENT	TESTING	SIMULATION
EFFESUS	✓	✓	✓
CO2OLBRICKS	✓	—	✓
CLIMATE FOR CULTURE	✓	✓	✓
SECHURBA	✓	—	✓
3ENCULT	✓	✓	✓
ALPINE SPACE	✓	—	✓

3.8. TECHNOLOGY AND SOFTWARE

In all projects, simulation software was used for analysis. Apart from that, in all projects, infrared thermography was utilized on buildings in areas for case studies. In the EFFESUS project, BIM, GIS, and LIDAR technology were also utilized. BIM technology was additionally utilized in the Alpine Space project (Table 28).

Table 28. Technology and Software Methods Information Regarding Projects

TECHNOLOGY AND SOFTWARE					
	BUILDING INFORMATION MODELING (BIM)	GEOGRAPHIC INFORMATION SYSTEM (GIS)	SIMULATION SOFTWARE	LIGHT DETECTION AND RANGING (LIDAR)	INFRARED THERMOGRAPHY (IR)
EFFESUS	√	√	√	√	√
CO2OLBRICKS	—	—	√	—	√
CLIMATE FOR CULTURE	—	—	√	—	√
SECHURBA	—	—	√	—	√
3ENCULT	—	—	√	—	√
ALPINE SPACE	√	—	√	—	√

3.9. FOLLOW-UP MONITORING CONTROL

Tracking, monitoring, and control systems are used in all projects. With technology and smart systems, buildings can be more energy efficient (Table 29).

Table 29. Follow-up Monitoring and Control Information Regarding Projects

FOLLOW-UP MONITORING CONTROL				
	FOLLOW-UP	MONITORING	CONTROL	AUTOMATION
EFFESUS	√	√	√	√
CO2OLBRICKS	√	√	√	√
CLIMATE FOR CULTURE	√	√	√	√
SECHURBA	√	√	√	√
3ENCULT	√	√	√	√
ALPINE SPACE	√	√	√	√

3.10. OUTCOMES

The data obtained as outputs in the projects and data sets on buildings and building communities were obtained through case studies conducted in all projects. Thus, data sets have been created to lead the way for energy-efficient improvements in similar situations and structures. Data sets were obtained for all buildings. Unlike the Alpine Space project, a web-based system was developed with the data set created. In CO2OLBRICKS, SECHURBA, and 3ENCULT Projects, rules and limits for energy-efficient retrofitting were defined. A decision support system (DSS) was created to determine the interventions to be made for improvements with the data obtained as a result of the projects. EFFESUS, Climate for Culture, 3ENCULT, and Alpine Space are the projects where decision support systems are seen. Unlike the other projects, a web-based tool was developed for the decision support system in the Alpine Space project. Training was organized for experts, management, and users for the project outputs, the rule of law, and the data obtained. It was observed that various trainings were provided within the scope of EFFESUS, CO2OLBRICKS, Climate for Culture, and 3ENCULT Projects (Table 30).

Table 30. Outcomes Information Regarding Projects

OUTCOMES					
	DATA SET	DECISION SUPPORT SYSTEM (DSS)	RULE LIMIT LAW	APPROACH METHOD	EDUCATION
EFFESUS	✓	✓	—	✓	✓
CO2OLBRICKS	✓	—	✓	✓	✓
CLIMATE FOR CULTURE	✓	✓	—	✓	✓
SECHURBA	✓	—	✓	✓	—
3ENCULT	✓	✓	✓	✓	✓
ALPINE SPACE	✓	✓	—	✓	—

4. CONCLUSIONS

As a result, a comprehensive approach model for energy-efficient improvement intervention approaches has been created in line with the inferences obtained from the analysis, comparison, and evaluations made for the energy-efficient improvement of historical buildings. In line with the inferences obtained from the analysis, comparison, and evaluations, the approaches and intervention model were determined in 9 sub-criteria. Thus, the study will guide the creation of intervention models for future studies with the inferences and recommendations of energy efficiency approaches in historical buildings.

Approaches: In our country, there are many historical buildings as cultural heritage buildings. These buildings should be considered comprehensively, and road maps should be created with a general energy-efficient improvement approach. Rather than considering buildings, building elements, or materials individually, they should be considered in a broad perspective. The efficiency obtained will increase by evaluating a texture, settlement, neighborhood, or city. At the same time, the size of the protected value is thus higher. Detailed studies should be carried out for the following stages according to building types, building elements, and material solutions.

Objectives: In energy-efficient retrofits, it is advantageous to consider energy efficiency as the primary objective and achieve sub-objectives. Steps should be taken to keep the heritage value in sustainable use. In addition to the high degree of impact of the improvements, they should be given equal importance to the conservation effect. In addition, cost-effectiveness is essential as extensive work requires new technology materials and systems. It plays a vital role in the decision-making process in the improvements to be made. In order to reduce the adverse effects of climate change and global warming, the durability of buildings is one of the most up-to-date approaches today. Reducing CO_2 and carbon emissions by reducing negative impacts through interventions is essential in this direction. Life cycle assessments should also be considered, and interventions should be decided for all interventions to be made.

Active Systems: Passive interventions for energy efficiency should be supported by improving existing solutions with today's technology or developing new solutions with active systems (such as heating, cooling, ventilation, and lighting).

Passive Systems: In the interventions to be made in the building envelope, on-site measurements, experiments, and simulations should be made, and improvement decisions should be taken regarding the building elements. While determining the interventions here, the most important criterion should be that the interventions should be made within the framework of conservation decisions and limitations and not deteriorate the original heritage values.

Renewable Energy Systems: The energy needed should be met with renewable, clean energy sources. These approaches can provide much more effective gains at the individual building scale and a settlement or city scale. Solar energy, in particular, is one of the most widely utilized. In addition, energy sources such as wind, biomass, and geothermal energy should be utilized for large-scale improvements.

Analysis Methods: Conducting detailed and comprehensive field studies is crucial for the identification and decision-making stages. Experiments should be conducted using data obtained from field studies, and the accuracy of the data should be supported by simulation software. Field studies should be supported by the technology and software to be used. Obtaining data from detailed material scale to settlement texture scale and creating detailed data sets with the data obtained are essential for making healthy decisions.

Technology and Software: The technology and software used are essential for on-site detection, current situation analysis, and data transfer to the future. The integrated operation of all technologies effectively determines the current situation and makes the best intervention decision. It is an essential criterion for historical buildings that the future follow-up of the planned intervention is also sustainable.

Follow-Up Monitoring Control: It is essential to consider follow-up, monitoring, control, and automation systems to ensure that productivity continues and is controlled after all interventions.

Outcomes: In addition to all these intervention approaches, it is also a critical stage to ensure the sustainability, dissemination, and continuity of multidisciplinary approaches in the field of energy and conservation, as well as to provide training and information to increase awareness.

Compliance with the Ethical Standard

Conflict of Interest*: The author(s) declare that they do not have a conflict of interest with themselves and/or other third parties and institutions, or if so, how this conflict of interest arose and will be resolved, and author contribution declaration forms are added to the article process files with wet signatures.*

Ethics Committee Approval*: There is no need for ethics committee approval in this article, the wet signed consent form stating that the ethics committee decision is not required has been added to the article process files on the system.*

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