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Retrofit Strategies for Energy Efficiency of Historic Urban Fabric in Mediterranean Climate

Meltem Ulu [1] and Zeynep Durmuş Arsan [2,*]

[1] Department of Architecture, Erciyes University, 38280 Kayseri, Turkey; meltemulu@erciyes.edu.tr
[2] Department of Architecture, Izmir Institute of Technology, 35430 Izmir, Turkey
* Correspondence: zeynepdurmus@iyte.edu.tr

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Abstract: Energy-efficient retrofitting of historic housing stock requires methodical approach, in-depth analysis and case-specific regulatory system, yet only limited efforts have been realized. In large scale rehabilitation projects, it is essential to develop a retrofit strategy on how to decide energy-efficient solutions for buildings providing the most energy saving in a short time. This paper presents a pilot study conducted at a neighborhood scale, consisting of 22 pre-, early-republican and contemporary residential buildings in a historic urban fabric in the Mediterranean climate. This study aims to develop an integrated approach to describe case-specific solutions for larger scale historic urban fabric. It covers the building performance simulation (BPS) model and numerical analysis to determine the most related design parameters affecting annual energy consumption. All the case buildings were classified into three main groups to propose appropriate retrofit solutions in different impact categories. Retrofit solutions were gathered into two retrofit packages, Package 1 and 2, and separately, three individual operational solutions were determined, considering a five-levelled assessment criteria of EN 16883:2017 Standard. Energy classes of case buildings were calculated based on National Building Energy Regulations. Changes in building classes were evaluated considering pre- and post-retrofit status of the buildings. For the integrated approach, the most related design parameters on annual energy consumption were specified through Pearson correlation analysis. The approach indicated that three buildings, representing each building group, can initially be retrofitted. For all buildings, while maximum energy saving was provided by Package 2 with 48.57%, minimum energy saving was obtained from Package 1 with 19.8%.

Keywords: energy-efficient retrofit; historic residential buildings; energy consumption prediction

1. Introduction

Many countries have introduced numerous policy measures and strategies on energy efficiency depending on national circumstances and political goals, together with increasing risks of climate change and global warming, rapidly depleting natural sources and rising energy demand/consumption [1]. There is an urgent need to implement energy-oriented solutions for buildings, since the building sector comprises the largest portion of energy saving potential. It is explicit that the building and construction sectors are the highest final energy-consumers, being responsible for 36% and 39% of energy- and process-related emissions at global level in 2018, respectively [2]. Particularly, residential buildings account for 22% [2] and 27.2% [3] of final energy consumption in 2018 in world and the EU-28 countries, respectively. In Turkey, the residential sector has the highest share of total energy consumption, with 24.5% in 2016 [4].

While the current attention is towards the upgrading of energy-efficiency policies and retrofit efforts on existing building stock, historic buildings are also a non-negligible contributor, since historic buildings constitute over 25% of total buildings [5] and more than 40% of residential buildings in

Europe were built before the 1960s [6]. In Turkey, the percentage of historic buildings built before 1945 is 6.1% [7]. Moreover, the largest share within officially registered immovable cultural properties belongs to residential buildings with 63% in 2019 [8].

Differently from other existing buildings, historic buildings form distinctive architectural and aesthetical characteristics in many urban areas, as well as keeping intangible elements, such as associations of historic people, events and aspects of social history, within cultural heritage values. They also comprise inherently sustainable characteristics in terms of material use, construction type, spatial decisions and topographic unity [9]. Energy-efficient retrofit of historic buildings is undoubtedly vital for ensuring their proper re-use to meet modern-day requirements, keeping away from desolation and demolition, enhancing comfort conditions, i.e., thermal and visual, and maintaining distinctive characteristics and heritage values.

Building conservation and energy efficiency are both key aspects for sustainable development which covers social, economic and environmental requirements and balances them in harmony. It is possible to improve the energy efficiency of historic buildings without compromising their historic fabric and distinctive characteristics [10]. The fact remains that the energy efficiency of historic buildings requires a special concern in comparison to existing one. This issue should be addressed in an interdisciplinary approach to find a convenient balance between conservation principles and energy-efficient retrofits.

Energy-efficient retrofit of existing buildings has become a prominent policy argument at both the national and international levels, specifically over the last 20 years. The European Commission (EC) enacted a series of policies and regulations addressing new and existing buildings to make them more energy efficient and reduce CO_2 emissions in the EU countries through Energy Performance of Building Directives (EPBDs) [11–13] and Energy Efficiency Directive (EED) [14]. The EC initially stipulated three key targets: reducing GHG emissions by 20%, increasing energy efficiency by 20% and increasing the share of renewable energy sources in energy consumption by 20% by 2020 [15]. Beyond the 2020 strategy, The EU drew longer-term low carbon economy and energy roadmaps in 2011. The low carbon economy roadmap set out target levels to reach the 2050 goal in a cost-effective way, a 40% reduction in emissions by 2030 and a 60% reduction by 2040, as well as a 25% reduction by 2020 [16]. The energy roadmap emphasizes that improving energy efficiency is a key driver in all decarbonization scenarios [17]. Recently, the recast EPBD also stipulates strong long-term renovation strategies aiming at achieving an energy-efficient and decarbonized European building stock, with indicative milestones for 2030, 2040 and 2050 [13].

As a candidate country for the EU, Turkey is upgrading its legislative efforts to be compatible with the policies of the EU. It prefaced with the first national standard, namely, the TS 825 Thermal Insulation Requirements for Buildings, which established the rules for thermal insulation in the buildings of Turkey in 2000 [18]. The Energy Efficiency Law, established in 2007, was promulgated aiming to increase energy efficiency, minimizing energy costs and ensuring the use of energy sources for a clean environment. Then, Energy Performance Regulation on Buildings was published in 2008. It obligates the building energy certification scheme, which includes information about energy classification categories and the minimum energy requirements of existing buildings for their renovation [19].

Although the EU Directives addresses the major aspects of the renovation of existing building stock and retrofitting technical elements and systems, there is no specific statement about retrofitting historic buildings. In the first EPBD 2002/91/EC, the EU left the decision about implementing minimum energy performance requirements for historic buildings to its member states [11]. The following directives revised and rearticulated this statement [12,14]. In other respects, the recast EPBD [13] promotes researching and testing of new solutions to improve the energy performance of historic buildings and sites, while safeguarding and preserving heritage value.

In Turkey, the Energy Performance Regulation on Buildings refers to a similar statement as specified in the first EPBD 2002/91/EC. The Article 2 (ç) in the Regulation indicates that energy-efficient interventions on the buildings that are officially registered as a cultural asset should be conducted by receiving the consultancy of competent authorities in a way not to affect building fabric and appearance [19]. In its 2023 projections, Turkey points out the necessity of energy improvements of existing buildings; however, there is no specific expression covering historic buildings [20].

Recently launched by the European Committee in 2017, the Standard EN 16883 Conservation of Cultural Heritage-Guidelines Improving the Energy Performance of Historic Buildings directly focuses on the energy efficiency of historic buildings. EN 16883: 2017 covers historically, architecturally or culturally valuable buildings, regardless of whether they are officially registered or not. It presents a systematic procedure about the identification of objectives for refurbishment based on various assessment categories, such as energy saving, heritage significance, economic viability, compatibility, selecting and evaluating interventions and deciding on the most appropriate ones while respecting heritage significance of buildings [21].

Consequently, there is no legal certainty about how to improve the energy efficiency of historic buildings while preserving their function, quality or character in building regulations of the EU and Turkey. Another concern is the lack of any protection procedure covering historic buildings, even if not legally protected. This situation poses a risk when it comes to physical alterations for those buildings constituting large part of historic urban centers [22].

The review of recent literature emphasizes that the lack of a specific protocol on the energy efficiency of historical buildings at an individual building level comes to the fore, as well as this lack being even more noticeable for urban scale approach [23]. Nevertheless, research on the energy efficiency of historic urban stock affirms that a certain number of publications have accelerated after 2010 in the European Countries. The course of studies is discussed in terms of diversity of the research topics, methodologies, focus groups and level of retrofit. Research topics are grouped under five sub-topics, consisting of energy efficiency, thermal comfort, environmental impact, economic impact and heritage value. Energy-efficient retrofit solutions addressing both individual cases and building stock are categorized in the surveyed publications. While individual building level solutions are related to building systems, equipment and building envelope, such as walls, floors, roofs, windows, doors and shutters, integration renewable energy sources and district heating are included in district scale solutions. Table 1 summarizes research topics and energy-efficient retrofit solutions for both building and district scale.

Improving energy efficiency while protecting the heritage value of historic buildings is an essential purpose for all studies. Additionally, some studies aim at improving thermal comfort [24–29], achieving carbon emissions reductions and assessing energy-efficient measures via life-cycle approach [30,31] and increasing economic performance with regard to cost-effectiveness [25,26,29–31] (Table 1).

District-level retrofit solutions have multiscale approach, comprising of the building scale and district scale. Regarding the building scale, the majority of studies deals with retrofit solutions on building envelope covering insulation of walls, floors and roofs and repairing or replacing door and window systems. Interior insulation of the external walls and improving windows are the most preferable ones. It is followed by improvements of the HVAC systems and equipment, while the integration of renewable energy systems has been in the minority due to concerns on building appearance and heritage value. Moreover, using weather stripping is the cheapest way to improve energy performance among the studies whilst still being effective (Table 1). Almost all studies combine single retrofit solutions, and then use these as multiple retrofit packages. Considering the district scale, Broström et al. (2014) [26] and Sugár et al. (2020) [32] propose the installation of a district heating system as a prominent solution. Bonomo and Benardinis (2014) also concentrate on the integration of solar PV technologies not only into the building but also the urban and landscape scale in a historical settlement in Italy [33].

Table 1. Categorization and main characteristics of the retrofit-related publications by a systematically reviewed literature.

References	Date	Country	Research Topics					Energy-Efficient Retrofit Solutions														
								Building Scale												District Scale	
			EE	TC	ENI	ECI	HV	EIW	IIW	CWI	IF	IR	IAF	WS	RRWD	IS	IHVAC	IEA	IRES	IRES	DH
Boarin and Davoli	2013	Italy	•		•		•	√	√		√	√			√						
De Berardinis et al.	2014	Italy	•	•		•	•	√	√						√						
Arumägi and Kalamees	2014	Estonia	•	•		•	•	√	√		√		√		√		√				
Alev et al.	2014	Estonia, Finland and Sweden	•	•			•	√			√		√		√		√	√			
Bonomo and De Benardinis	2014	Italy	•			•	•												√	√	
Broström et al.	2014	Sweden	•	•		•	•	√	√				√	√	√		√				√
Eriksson et al.	2014	Sweden					•	√													
Giombini and Pinchi	2015	Italy	•				•	√	√			√			√						
Tadeu et al.	2015	Portugal	•		•	•	•	√			√	√			√		√				
Egusquiza et al.	2015	Spain	•			•	•		√			√					√	√			
Arumägi et al.	2015	Estonia	•	•			•	√			√	√			√						
Fatiguso et al.	2015	Italy	•				•			√		√	√								
Egusquiza et al.	2018	Spain	•			•	•	√	√	√		√		√	√						
Belpoliti et al.	2018	Italy	•				•	√	√		√	√			√		√				
Blumberga et al.	2020	Latvia	•		•	•	•										√			√	
Sugar et al.	2020	Hungary	•				•	√	√		√	√			√		√				√
Caro and Sendra	2020	Spain	•	•	•		•					√			√	√					

An energy-efficient retrofit approach at district scale differs from the individual building level. Various studies have developed a neighborhood scale approach, instead of one-by-one approach, to assess the energy-efficient retrofit potential of historic building stock. They identify buildings as representative or archetype cases which characterize a specific building group to evaluate the outcomes on these cases by extrapolating to wider scale. The reason is to speed up the decision-making process in determining retrofit solutions and provide a higher level of energy-efficient improvements [23,24,27–30,34]. Several studies also present overall methodologies on deciding and evaluating the effects of energy-efficient retrofit solutions while avoiding the potential risks for historic building stock [23,31,32,35]. Eriksson et al. (2014) presented a methodology developed for EU Historic Districts' Sustainability (EFFESUS) research project to analyze the impacts of energy-efficient measures on heritage significance in a historic district in Visby, Sweden [35]. Egusquiza et al. (2018) suggested a method that provides early-stage suitability assessment of energy conservation measures (ECM) for historic urban areas within a multi-scale approach through ICOMOS guidance on Heritage Impact Assessment [23]. ECMs are evaluated to decide their impact on heritage value and Santiago de Compostela, Spain was selected to test this method, as supported by 3D models. In the study of Sugar et al. (2020), the heritage-respecting energetic retrofit methodology was developed for the historic building stock of Budapest, Hungary, based on the EPBD [32]. Blumberga et al. (2020) presented a decarbonization strategy of urban block in the historic center of Riga, Latvia by discussing the impact of energy efficiency measures on historic heritage values [31].

When planning large-scale retrofit process, extensive data collection and energy investigations are inevitable to define building characteristics, energy behavior and energy saving potential of building stock [23,31,32,34,36,37]. Building categorization is another significant indicator to determine urban typologies and, therefore, appropriate solutions are to be applied in accordance with district scale. Multiple studies list various categorization criteria, such as type of building, purpose of use, number of floors, building geometry, construction year, building system and remarkable architectural characteristics and degree of protection, as well as heritage value. The most notable one is the heritage value [23,26,29,32,38,39].

It has been seen that building performance simulation (BPS) tools are widely used not only in earlier stages of a design process for sustainability but also in analyzing existing building performance and evaluating potential retrofit solutions to attain more energy-efficient historic buildings. They are useful for obtaining fast and actual results in a short time, especially in larger scale studies [24,27,29,39].

The above-mentioned studies make explicit that energy efficiency and heritage value protection are hot topics in discussed publications. Energy-efficient retrofit of historic buildings and urban areas is a delicate matter that needs to be considered in an interdisciplinary way. Therefore, the retrofit process of historic buildings requires a distinctive roadmap in comparison to the other existing buildings. All retrofit works on historic buildings are specific in their context. Before implementing a retrofit solution, in attempt to improve energy efficiency of historic buildings, a number of principles should be thoroughly considered: intervention should be kept at a minimum level and retrofits should be reversible, compatible and respectful to the original fabric, distinctive characteristics and heritage value of buildings.

Historic districts are well-defined areas by distinctive characteristics in urban areas, in terms of size, fabric, form, construction, material used and density, as well as heritage value, integrity, memory and perception in modern urban environment. It is necessary to turn historic urban areas into an energy-efficient model for sustainable development in communities by balancing between the conservation of historic buildings and sustainability requirements to ensure their continuity for future generations while protecting their heritage value. The fact remains that, in large scale rehabilitation projects, the requirement of developing a retrofit strategy is crucial regarding the question of how to decide solutions for buildings which provide the most energy saving in a short time. Since large scale retrofit studies require extensive data collection to define building characteristics, field survey takes a long time, and the economic impact of this is high.

In historic urban fabrics of Turkey, street and/or façade rehabilitation projects are generally conducted at a neighborhood scale. They are limited to various efforts such as improving the physical appearances of buildings and façade components, painting of buildings' façades and fixing street furniture and decoration elements by protecting fabric and the distinctive characteristics of the buildings and streets. The key innovation of this study is to expand this approach from the energy-efficient point of view. The main aim of the study is to develop an integrated approach to identify case-specific energy-efficient solutions toward retrofit strategies for larger scale historic urban fabric.

The present study expands upon the current literature by bringing a distinctive decision support methodology about how to decide energy-efficient retrofit solutions at a neighborhood scale, consisting of both historic and contemporary residential buildings, in a short time and with a limited budget. It conveys an integrated roadmap to speed up the decision-making process in determining more precise and context-specific retrofit solutions for larger scale historic urban fabric. Moreover, this study will be the first in Turkey which considers historic building retrofit from an energy-efficiency point of view at the urban scale.

2. Case Study

The study has been carried out in the neighborhood located in Basmane District, the quite old Ottoman residential area of Izmir, Turkey. The city is situated on the west coast of the country, next to the Aegean Sea, and thus has a Mediterranean climate; summers are hot and humid, while winters are mild and rainy. The Basmane District constitutes a considerable part of the Kemeraltı Urban Historical Site within the historic urban residential texture. 1273 Street, as the selected neighborhood, is in a residential zone which hosts qualified historic buildings within Basmane District. It lies on the east–west direction with a 38.25° N latitude and a 27.08° E longitude and is 12 m elevation above the sea level. The neighborhood has a key position due to its proximity to Basmane Historic Train Station, Agios Voukolos Church and the Altınpark Archaeological Excavation Area of the antique Smyrna City. In the last decade, it has been mostly populated by transboundary migrants, especially Syrian refugees, as the temporary residential area. The historic urban fabric of neighborhood has been damaged.

Izmir Metropolitan Municipality prepared the Façade Rehabilitation Project for 1273 Street in 2013 to regenerate the neighborhood, requiring intervention strategies for improving security and rehabilitating living conditions. In addition, the municipal boards wanted to interfere with the existing conditions, at least, to improve pedestrian routes for local and foreign tourists. However, any energy-efficient approach was not considered during the rehabilitation process. Therefore, this study has been prepared as a proposal for Izmir Metropolitan Municipality to provide local, applicable and quick retrofit solutions with the most energy saving potential within the limited project budget.

A total of 22 buildings, covering historic and contemporary buildings which lie on 1273 Street, are investigated (Figure 1). There are 4 solely commercial and 18 residential buildings, 3 of which have shops on their ground floors. Both historic and contemporary buildings coexist in the street, situated in adjacently. Of the 22 buildings, 13 are historic ones, in total: 11 of them are officially registered, while the remaining 2 are determined as non-registered in character. The rest are the contemporary buildings. The number of floors varies between one and three. A large majority of extant historic buildings were built between the end of 19th and the first quarter of 20th centuries. A total of 20 buildings were constructed with stone or a brick masonry system. There are only two reinforced concrete buildings. The oriels on the second floors designed as a protrusion with wooden or iron structure, ornamentations on iron doors and stone wall order are typical periodic characteristics of historic buildings (Figure 2).

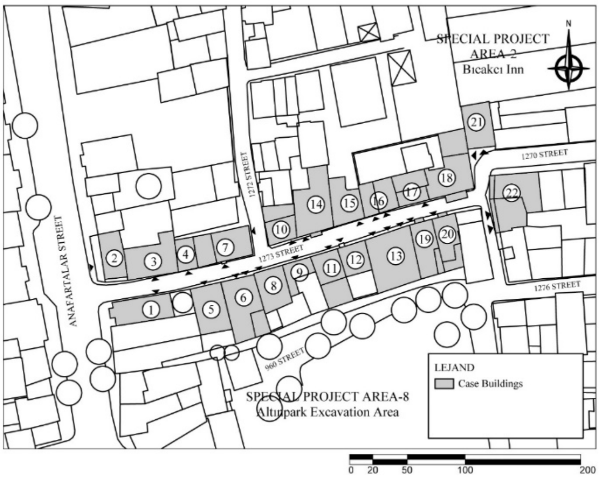


Figure 1. Numbered case buildings in 1273 Street. Source: modified from the drawings of Konak Municipality.

Figure 2. View from 1273 Street.

3. Materials and Methods

This study proposes a method to develop retrofit strategies about the energy efficiency of existing buildings in historic urban district, including both historic and new buildings via appropriate solutions only for the buildings' envelopes. The retrofit strategy considers the impact assessment criteria and scale of retrofit measures for historic buildings, presented by a five-level assessment scale of EN 16883:2017 [21].

The identification process of retrofit strategies is composed of seven main stages: data collecting, data processing, creating possible retrofit solutions, categorizing buildings, assessing retrofit solutions, analyzing data and presenting results (Figure 3). This method starts with the quick field survey, i.e., data collection conducted in several levels. First, documents about the case area are obtained to get preliminary information. The data sheets are created to characterize of the buildings in the case area. Then, on-site measurements on the buildings' envelope are carried out through data sheets. Additionally, it is attempted to get information about the buildings in use from the users of buildings.

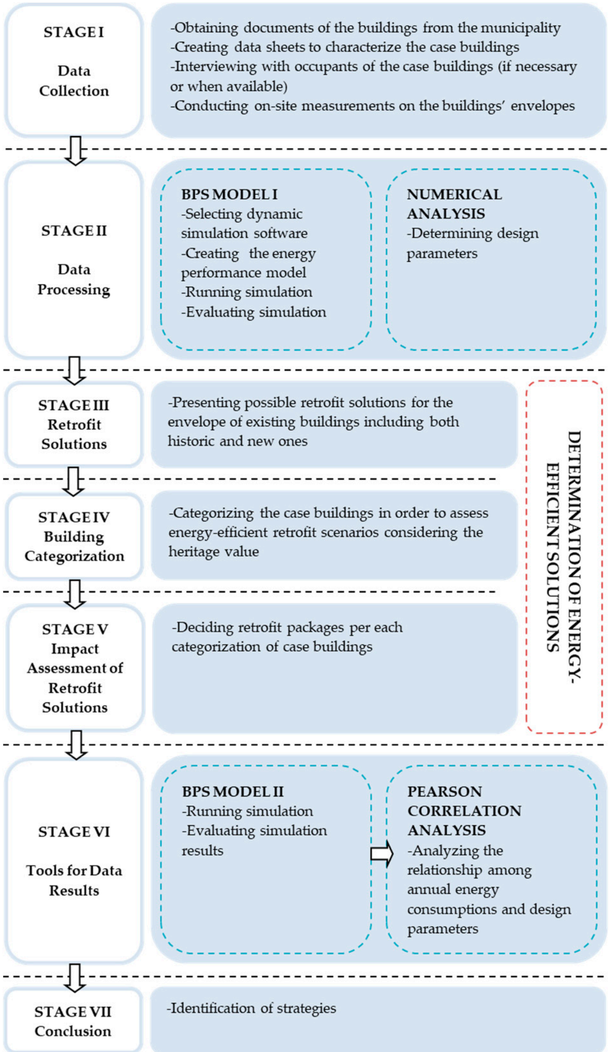


Figure 3. Identification process of energy-efficient retrofit strategies.

The second stage continues with the characterization of the tool selected to put in the process of the method and explanation of how they work. The case area is modelled in dynamic simulation software to calculate the energy consumption of the case buildings in existing conditions. This building performance simulation (BPS) model represents the base model of case buildings. The next three stages lay emphasis on the energy-efficient retrofit strategy for the case buildings. Accordingly, the third stage discusses and presents possible energy-efficient solutions for the retrofitting of existing buildings, covering new and historic ones. It primarily concerns the retrofit solutions of the components of buildings' envelopes, including external walls, floors, roofs, oriels, windows and doors. The fourth stage goes forward with the categorization of case buildings considering the heritage value.

The fifth stage aims at deciding possible packages of retrofit solutions to provide energy savings. It presents the most appropriate solutions and eliminates the inappropriate ones for the categorized case buildings. Therefore, a five-level impact assessment scale for retrofit solutions is investigated for historic buildings. In the sixth stage, new building performance models for retrofit solutions are created and simulated for each retrofit package. After a comparative study between the base case simulation results and retrofitted ones, the relationships between annual energy consumptions and design parameters are presented. In the seventh stage, possible retrofit strategies for the case buildings are introduced.

3.1. Data Collection

Data collection, aiming to gather the required adequate and reliable information about buildings' envelope through a quick survey, is composed of two steps: pre-study and field survey. The former includes the collection of any research and official documentation about case area and buildings. The latter is mainly grouped under site investigations: creating data sheets, conducting on-site measurements for components of buildings' envelopes and interviews with the buildings' users. Data collection was held in two separate time periods of 20–25 June 2014 and 10–15 February 2016.

Documentation about the case area and its surrounding were obtained from the Street Rehabilitation Project Proposal of Izmir-Konak Municipality held in 2013. Particularly for historic buildings, inventory forms of 11 officially registered buildings were provided by the Izmir Metropolitan Municipality Directorate of Historic Environment and Cultural Properties. These forms provide information about the degree of protection status of historic buildings; they do not include any construction drawings and details. Except for three registered buildings, the architectural drawings, such as floor plans and sections of the buildings, were not reached during the site investigations.

Data sheets, composed of a double-sided page in A4 format, were prepared for each building in the case area. The aim was to characterize the current status (historic/old/new) of the case buildings, e.g., physical (envelope) qualities, construction details and surrounding features. The type of data about building envelope and surrounding required by BPS model were determined. Observation, measurements and photography techniques were used in collecting required data for the data sheets.

On-site measurements were carried out for external walls, floors, roofs, oriels, windows, external doors and shutters to characterize construction materials with simple sections, elevations and plan drawings. Dimensions of the structural components were identified via a laser distance meter and then noted on the relevant section in the data sheets. Moreover, the height and width of surrounding buildings were measured by laser distance meter to identify the adiabatic surfaces of the adjacent neighboring buildings and their shading effect. Through the measurements, the following specifications about the envelope are clarified and corrected:

- width–length–height of the external walls;
- width–length of the external floors (external floor below the oriels and external floor over the entrances designed as a door niche);
- width–length–height of the windows and their position on the external wall surfaces;
- width–length–height of external doors and their position on the external wall surfaces;
- width–length–height of the oriels;
- width–length–height of the shutters;
- width and length of the eaves of the roofs.

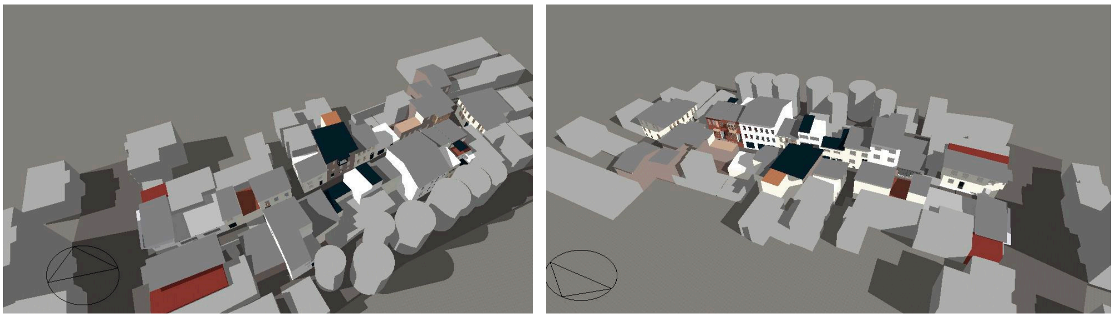
Moreover, traditional building material samples collected from immediate environment were tested to determine their thermal properties. The thermal conductivity (W/mK) of various stone and solid brick samples was measured by the Quick Thermal Conductivity Meter (KEM Q500 with a measuring range of 0.023 to 12 W/mK and a precision of ±5% reading value per reference plate) [40] in the Geothermal Energy Research and Application Centre of Izmir Institute of Technology (IZTECH JEOMER).

Short interviews with the occupants of several buildings were conducted in order to obtain adequate information about the case buildings, i.e., the purpose of use, number of occupants/users, user profile, construction date, how the buildings are heated and cooled and type of fuel used.

3.2. Data Processing

3.2.1. BPS Model

A reliable and verified building performance simulation (BPS) software, DesignBuilder v.5.2, was used for model creation, energy simulation and analysis, as well as decision-making processes [41]. Model creation of the case buildings was prepared according to the most recent field survey which was completed in 2016 (Figure 4). Through data processing, the base case models, which indicate the real status of each case building, and then the retrofitted case models to assess the energy-efficient retrofit solutions were prepared. Seasonal energy consumption for heating and cooling and annual energy consumption were analyzed. The model geometry of case buildings was simplified in line with the purpose of the study: identification of strategies for energy-efficient retrofit via quick field survey. The model abstraction was conducted for both the façades and layout plans of buildings.



(**a**) (**b**)

Figure 4. Model of case buildings and their surrounding from the (**a**) south and (**b**) north direction in DesignBuilder Software.

3.2.2. Numerical Analysis

This study addresses a number of design parameters to focus on prominent geometric variables regarding building form, i.e., the envelope characteristics of case buildings. It discusses total seven design parameters:

- DP1: Total surface area (m^2) to conditioned volume (m^3) ratio (S/V);
- DP2: Total window area (m^2) to total wall area (m^2) ratio;
- DP3: Window area (m^2) to wall area (m^2) ratio (main façades of buildings face to 1273 Street);
- DP4: Shape factor (building length (m) to depth (m));
- DP5: Usable ground floor area (m^2) to conditioned volume (m^3);
- DP6: Total usable floor area (m^2) to conditioned volume (m^3);
- DP7: Building height (m) to plan depth (m).

Bivariate Pearson correlation coefficient analysis was selected to understand empirically the relation between the design parameters and annual energy consumption of the case buildings. It is a statistical analysis method used to determine whether there is a linear relationship between two numerical variables, and, if any, the degree of the relationship. The Pearson correlation coefficient is expressed in 'r'. It can take a range of values from +1 to −1, depending on whether the relationship is positive or negative, respectively [42] (Table 2):

- r = −1, a perfect negative linear relationship. One variable increases, the other decreases or one variable decreases while the other increases;
- r = 1, a perfect positive linear relationship. One variable increases, the other increases or one variable decreases while the other decreases;
- r = 0, no relationship. There is no relationship between two variables.

Table 2. Range of values and relation of Pearson correlation coefficient.

R	Relation
0.00–0.25	Very low
0.26–0.49	Low
0.50–0.69	Medium
0.70–0.89	High
0.90–1.00	Perfect

3.3. *Determination of Energy-Efficient Solutions*

In order to determine energy-efficient solutions for historic urban fabric and find the most appropriate solutions for building envelope, a set of actions were organized, starting with a preliminary analysis of possible retrofit solutions by taking into account a literature survey, including guidelines, standards and publications. This section continues with the categorization step. A total of 22 buildings were classified and characterized by number of qualitative and quantitative data. Afterwards, a pre-assessment was conducted to find the best retrofit solutions by excluding inappropriate ones and identify a series of acceptable measures. After this process, retrofit solutions were grouped under retrofit packages by combining the best solutions. This step served the purpose of revealing which packages were most appropriate toward the targets of the study by evaluating and comparing different retrofit scenarios with each other and the base case. The final step was composed of the decision and presentation of retrofit packages (Figure 5).

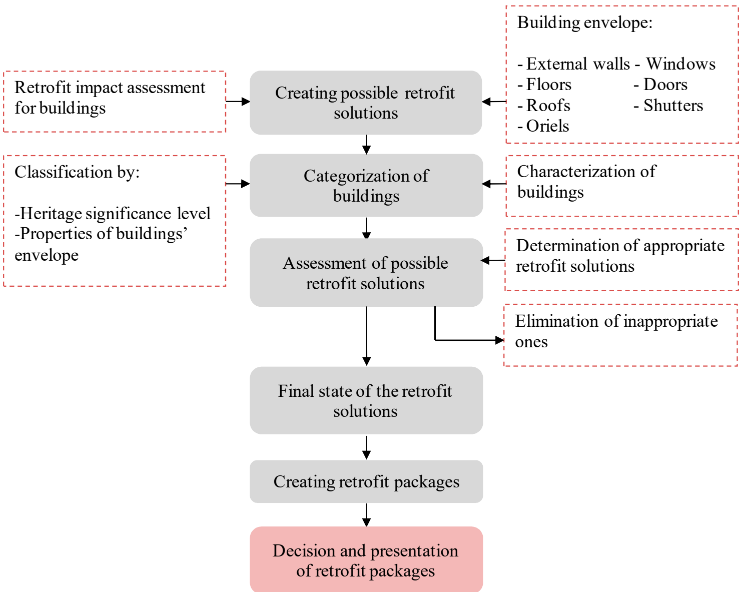


Figure 5. Determination process of energy-efficient solutions of the study.

3.3.1. Retrofit Impact Assessment for Historic Buildings

Historic buildings differentiate in two major ways that can affect energy retrofits in comparison with other building categories. The first one is physical characteristics, such as the complexity of geometry, method of construction, used materials and existence of inherently passive climatic strategies. The second one is conservation principles, since historic buildings are held to account for established conservation principles to preserve their historic fabric and distinguishing characters [43].

It is essential to point out the need for providing a convenient balance between building conservation principles and energy-efficient improvements. Implication of a well-understood energy-efficient retrofit approach protects architectural, aesthetic and heritage values, reduces energy bills and improves comfort conditions and health of occupants, as well as increases the value and prolongs the life of historic buildings.

As such, in existing non-historic and contemporary buildings, it is possible to develop energy-efficient strategies for historic building envelope and system and equipment. However, a standardized retrofit process cannot be conducted, and accordingly, a method for retrofit impact assessment becomes inevitable in determining the best retrofit solutions that can be implemented to historic buildings. Therefore, energy-efficient retrofitting of historic buildings requires an interdisciplinary approach [44].

The retrofit impact assessment has an approach based on certain criteria for each type of existing building. These criteria can be grouped under different topics, such as energy aspect, i.e., energy saving, embodied and operational energy, and economic aspect, indoor and outdoor environment and hygrothermal performance, i.e., durability, moisture risk and thermal transmittance. However, the criteria and process of retrofit differ by conservation principles for historic buildings [42]. Thus, heritage value protection commonly plays a leading role in the assessment of historic buildings [26,35,43,45]. The criteria for retrofit impact assessment specific to historic buildings can be scrutinized under specific subtopics: retrofit effects on building envelope, i.e., visual and spatial effects from the interior and exterior, and properties of retrofit materials, i.e., reversibility, damage potential and fabric compatibility [35,46] (Table 3).

Table 3. Criteria for retrofit impact assessment.

Criteria for Retrofit Impact Assessment					
				Criteria for Heritage Value Impact Assessment	
Şahin et al., 2015 [46]	**Eriksson et al., 2014 [35]**	**Broström et al., 2014 [26]**	**Webb, 2017 [43]**	**Grytli et al., 2012 [46]**	**Eriksson et al., 2014 [35]**
Energy saving	Indoor environment	Energy savings	Global environment	Reversibility	Visual
Cultural heritage values	Fabriccom patibility	Economic aspect	Building fabric	Visibility	Physical
Durability	Heritage significance	Heritage values	Indoor environment	Effects on the interior or the exterior	Spatial
Economic return	Embodied energy	Moisture	Economics		
Moisture	Operational energy	Indoor environment			
Indoor environment	Economy				

An overview about the retrofit impact assessment of various scientific studies and guidelines are presented based on two major criteria, including heritage value protection and energy saving. The assessment was conducted for all building components covering walls, floors, roofs, oriels, openings and shutters and a range of retrofit solutions in accordance with these building components. Moreover, the retrofit assessment of sources was interpreted by utilizing the five-level assessment criteria introduced by EN 16883:2017 (Figure 6 and Table 4).

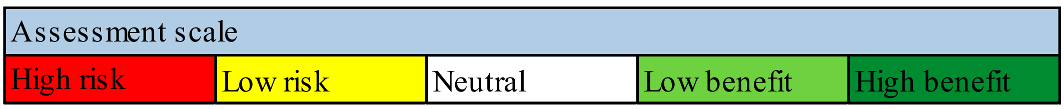


Figure 6. Five-level assessment scale for retrofit impact assessment [21].

Table 4. Retrofit solutions for the building envelope based on retrofit impact assessment (red: high risk; yellow: low risk; white: neutral; light green: low benefit; dark green: high benefit) (Sources: 1, [46]; 2, [47]; 3, [48]; 4, [49]; 5, [50]; 6, [46]; 7, [26]; 8, [51]; 9, [10]; 10, [52]).

Components of Building Envelope	Type of Retrofit	Sources	Retrofit Impact Assessment	
			Heritage Value Protection	Energy Saving
All components	Weather stripping/draught proofing	1, 5, 6, 7, 8, 9, 10	yellow, white	light green, dark green
External walls	External insulation	1, 3, 4, 6, 7, 8, 9	red, yellow	dark green
	Internal insulation	2, 3, 4, 6, 7, 8, 9, 10	yellow, white	dark green
Floors	Insulation of basement floor	1	yellow	dark green
	Insulation of ground floor	1, 6, 8, 9	red, yellow, white	light green, dark green
	Insulation of attic floor	1, 6, 7, 8, 9	yellow, white	light green, dark green
Roofs	Insulation of roof at rafter level	1, 4, 5, 6, 8, 9	yellow, white	light green, dark green
	Insulation of flat roof	4, 9	yellow	light green
Windows, doors and shutters	Adding secondary glazing on existing windows	2, 5, 7, 9, 10	yellow, white	dark green
	Changing windows with double/triple glasses	2, 6, 7, 9	red, yellow	dark green
	Changing windows with low-e double/triple glasses	2		dark green
	Changing/improving shutters	8, 9, 10	red, yellow	light green
	Changing/improving doors	8	red, yellow	light green
	Shutter control		white	light green
	Nighttime ventilation		white	light green
Oriels	Use of oriels as sun space		white	light green

According to the retrofit assessment, external insulation of walls, ground floor insulation, changing/improving windows, doors and shutters predominantly result in high risk on the heritage value and historic building character, while they provide substantial energy savings. Internal insulation of walls, basement floor insulation, attic floor insulation, flat roof insulation and adding a secondary glazing on existing windows have less risk on the heritage value, while they provide low benefit for energy efficiency. Implementation of weather stripping and roof insulation at rafter level have no risk on the heritage value and building appearance, as well as presenting moderate energy savings. Finally, shading control, night-time ventilation and use of oriels as sun space can be considered as the retrofit solutions without risk for the heritage value, because they do not cause any change on buildings' envelopes.

3.3.2. Possible Retrofit Solutions for Building Envelope

A list of possible energy-efficient solutions was addressed to develop the retrofit strategies for case buildings, including both historic and contemporary ones. Among a wide range of possible energy efficient retrofit solutions based on the literature survey, only 17 envelope-related retrofit solutions were selected (Table 5):

Table 5. Possible retrofit solutions for building envelope based on the literature survey.

For All Heated Zones	
Draught Proofing/Weather Stripping	
Walls External insulation of walls Internal insulation of walls	**Roofs** Insulation of flat roof Insulation of pitched roof
Floors Insulation of basement floor Insulation of ground floor Insulation of attic floor Insulation of external floors Insulation of oriels' ground floor Insulation of oriels' attic floor	**Windows and doors** Changing windows Adding a secondary glazing to existing windows Changing doors Use of oriels as a sunspace

3.4. Categorization of Buildings

In this study, a categorization process was conducted for the case buildings by characterizing according to their heritage values and architectural characteristics. This process aims at ensuring the most appropriate energy-efficient solutions by properly matching the retrofit packages with each building category.

Categorization starts with the heritage significance level, which is of top priority because of the most decisive and distinctive criteria at the first stage of categorization. It continues with characterizing the architectural components of building envelopes, i.e., walls, floors, roofs and oriels affecting the number and type of retrofit solutions produced for each building and how they work and are applied to building structure. The availability of basement floors and oriels in the case buildings were initially selected as criteria after the selection of the heritage significance level.

In accordance with the categorization process, the case buildings were gathered under three main groups based on the heritage significance level of buildings. These groups are officially registered historic buildings named Group 1 buildings, with non-registered historic buildings named Group 2 buildings and contemporary (non-historic) buildings named Group 3 buildings (Figure 7)

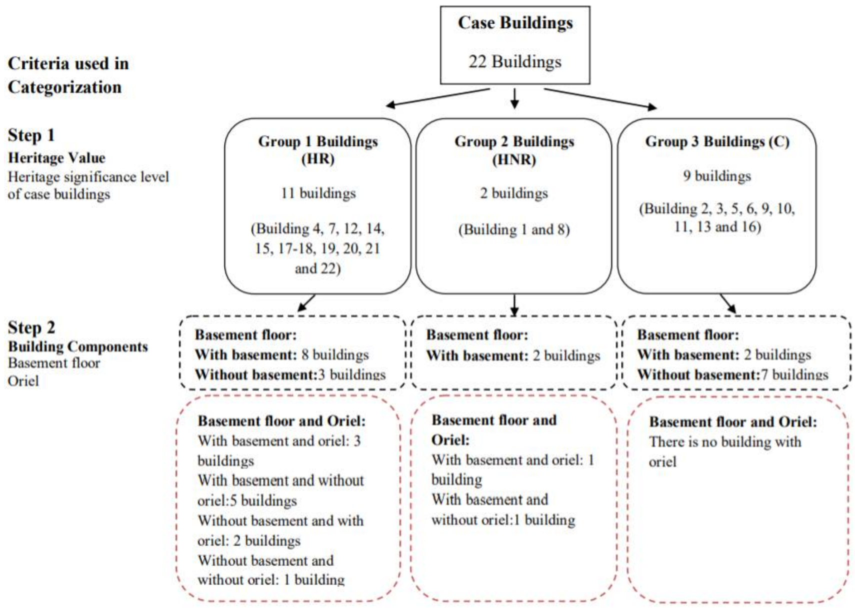


Figure 7. Categorization of buildings.

Group 1 buildings were solely composed of 11 officially registered buildings, encoded as "historic registered (HR)". Two buildings, representing Group 2 "historic non-registered (HNR)"—were not officially registered buildings but they were in harmony with the officially registered ones in terms of the physical, visual and material characteristics of the historic buildings' envelopes. Group 3 buildings were non-historic ones, consisting of nine buildings and characterized as "contemporary (C)" buildings.

3.5. Impact Assessment of Possible Retrofit Solutions for Building Groups

3.5.1. Impact Assessment of Possible Retrofit Solutions for Group 1 Buildings

First, defining the retrofit targets is of importance to properly assess the energy-efficient retrofit solutions and decide the appropriate ones for buildings. Several targets are specified for Group 1 buildings:

- to produce the energy-efficient retrofit solutions primarily considering the heritage value of case buildings;
- to provide as much energy saving as possible while protecting the heritage value of case buildings;
- to select the retrofit solutions as natural, breathable, reversible and compatible with the historic fabric, character and façade components of case buildings;

- to select the insulation materials to meet TS 825 Thermal Insulation Requirements, although there is no description about officially registered historic buildings in the Energy Performance Regulation on Buildings of Turkey [18].

After the definition of retrofit targets, 18 possible energy-efficient retrofit solutions for Group 1 buildings were evaluated based on the retrofit impact assessment through utilizing the five-level assessment criteria introduced by EN 16883:2017 (see Figure 6 in Section 3.3.1). As a result of the assessment, all retrofit solutions were gathered under three risk groups, based on the heritage value: high-risk solutions (red), low-risk solutions (yellow) and neutral solutions (white). Additionally, grey colored boxes show that there is no solution defined for the case buildings (Table 6).

Initially, three retrofit solutions, including the external insulation of external walls, changing windows and doors, were specified the high-risk solutions for the heritage value after the assessment. Therefore, they were excluded from the scope of the solutions for Group 1 buildings.

Six retrofit solutions were determined as the low-risk solutions after the heritage value impact assessment. These solutions are considered to have less impact on the heritage value and the buildings' appearances while causing changes on the buildings' constructions. The retrofit solutions with low risk were:

- internal insulation of external walls;
- internal insulation of oriel wall;
- insulation of oriels' ground floor;
- insulation of oriels' attic floor;
- insulation of the external floors (floor of protrusion and floor above entrance);
- adding secondary glazing to existing windows.

Considering the heritage value impact assessment, six retrofit solutions were determined as the neutral solutions causing physical change on buildings' envelope. These solutions improve the energy efficiency of Group 1 buildings without damaging the heritage value. The neutral retrofit solutions were:

- weather stripping to improve air-tightness of the building envelope;
- insulation of ground floor;
- insulation of attic floor;
- insulation of flat roof;
- insulation of oriels' roof;
- insulation of pitched roof.

The remaining three retrofit solutions were the passive solutions related to building operation. They were also entitled as the neutral solutions which do not cause any physical change on the buildings' envelopes (white color shown in building operation section of Table 6. These retrofit solutions were the following:

- use of oriels as a sunspace;
- night-time ventilation;
- shading control.

After the determination of appropriate retrofit solutions based on the heritage value impact assessment for Group 1 buildings, some of the retrofit solutions were grouped under the retrofit packages while some of were individually assessed. The neutral retrofit solutions causing physical changes on buildings' envelopes were included in a package named Package 1, separately simulated for Group 1 Buildings. Low-risk solutions for Group 1 buildings were not being separately evaluated, since they are not a foremost option in terms of preference and application priority. Therefore, Package 2 is generated by adding the low-risk retrofit solutions to Package 1 solutions and then evaluated. Moreover, operational solutions were not grouped, in order to observe their individual effects on the buildings' envelopes. Table 7 presents all retrofit solutions and packages determined for Group 1 buildings.

Table 6. Heritage value impact assessment for 18 energy-efficient retrofit solutions of Group 1 buildings (red: high risk; yellow: low risk; white: neutral; gray: no solution).

	Possible Retrofit Solutions	Group 1 B4	B7	B12	B14	B15	B 17-18	B19	B20	B21	B22	
Change on building envelope	External insulation of ext. wall	red	red	red	red	red	red	red	red	red	red	Eliminated Solutions
	Changing windows	red	red	red	red	red	red	red	red	red	red	
	Changing doors	red	red	red	red	red	red	red	red	red	red	
	Internal insulation of ext. wall	yellow	yellow	yellow	yellow	yellow	yellow	yellow	yellow	yellow	yellow	Package 2
	Insulation of oriel wall	gray	yellow	yellow	yellow	gray	yellow	yellow	gray	gray	gray	
	Insulation of oriel attic floor	gray	yellow	yellow	yellow	gray	yellow	yellow	gray	gray	gray	
	Insulation of oriel ground floor	gray	yellow	yellow	yellow	gray	yellow	yellow	gray	gray	gray	
	Insulation of external floor	gray	yellow	yellow	yellow	gray	yellow	yellow	yellow	gray	yellow	
	Adding secondary glazing	yellow	yellow	yellow	yellow	yellow	yellow	yellow	yellow	yellow	yellow	
	Insulation of flat roof	gray	white	gray	white	white	white	white	white	gray	gray	
	Insulation of oriel roof	gray	gray	white	white	gray	white	white	gray	gray	gray	
	Insulation of pitched roof	white	white	white	white	white	white	white	white	white	white	Package 1
	Weather stripping	white	white	white	white	white	white	white	white	white	white	
	Insulation of ground floor	gray	gray	white	gray	white	white	white	white	white	white	
	Insulation of attic floor	white	white	white	white	white	white	white	white	white	white	
Building Operation	Use of oriels as sunspace	gray	white	white	white	gray	white	white	gray	gray	gray	Operat. solutions
	Shutter control	gray	white	gray	white	gray	white	gray	gray	white	white	
	Nightime ventilation	white	white	white	white	white	white	white	white	white	white	

Table 7. Determined retrofit solutions and packages for Group 1 buildings.

Group 1 Buildings		
Package 1 (Neutral Related to Building Envelope)	**Package 2 (Combination of Neutral and Low-risk)**	**Individual Operational Solutions (Neutral Related to Building Operation)**
Insulation of flat roof Insulation of oriel roof Insulation of pitched roof Weather stripping Insulation of ground floor Insulation of attic floor	Internal insulation of external wall Insulation of oriel wall Insulation of oriel attic floor Insulation of oriel ground floor Insulation of external floor Adding secondary glazing Insulation of flat roof Insulation of oriel roof Insulation of pitched roof Weather stripping Insulation of ground floor Insulation of attic floor	Use of oriels as sunspace Shutter control Nightime ventilation

Specifications about Package 1 for Group 1 buildings: Package 1 aspired to enhance the energy efficiency of Group 1 buildings without damaging the heritage value. The package contained an implementation of weather stripping to improve air-tightness of the building envelope, insulation of attic floor, insulation of flat roof, insulation of oriels' roof, insulation of pitched roof and insulation of ground floor. Considering air-tightness improvements, the air exchange rate (ACH) was assumed to have improved from 0.7 h^{-1} to 0.4 h^{-1} in heated zones and from 0.9 h^{-1} to 0.7 h^{-1} in unheated zones to repair the cracks and holes on the building envelope. For floors, ground floor and attic floor insulation existed in Package 1. On the other hand, regarding the ground floors of some buildings, it was decided that they should not undergo a change during the retrofit interventions due to their structural composition and historic material properties.

Specifications about Package 2 for Group 1 buildings: Package 2 was intended to reveal the effects of both neutral and low risk retrofit solutions by providing as much as energy saving for Group 1 buildings as possible. Package 2 presented the combination of the low-risk and neutral solutions named (Package 1). The content of the low-risk solutions was composed of six retrofit solutions, including internal insulation of external wall, insulation of oriel wall, insulation of oriels' attic floor and oriel ground floor and roof, insulation of the external floors (floor of protrusion and floor above entrance) and adding secondary glazing to existing windows.

Considering the walls, internal insulation of external wall and oriel wall were implemented for heated spaces. If there was a case building with a gable roof, the gable walls were also insulated from inside. Moreover, external wall surfaces, as an adiabatic, were not insulated.

Specifications about Insulation Materials for Group 1 buildings: Determination of insulation material carries importance to protect the heritage value and fabric of historic buildings. Therefore, the use of natural, breathable and reversible materials was beneficial for minimizing the risks, i.e., moisture generation, on historic building construction and components. Wood fiber board and sheep wool were selected as the internal insulation material for Group 1 buildings.

Installation of secondary glazing was selected to provide an effective insulation for historic windows and limit draughts without changing any components of windows and damaging their character and heritage values. However, changing windows (glazing and frame) was envisaged on the façades of some Group 1 buildings. As for floors, the ground and attic floor of the oriels and external floors such as ground floor of protrusions and floors above the buildings' entrances were also included in low-risk solutions. Overall heat transfer coefficient targets to meet TS 825 Thermal Insulation Requirements for Buildings were achieved after the retrofits.

3.5.2. Impact Assessment of Possible Retrofit Solutions for Group 2 Buildings

Identified retrofit targets for Group 2 buildings:

- to select and evaluate the energy-efficient retrofit solutions primarily considering the historic character and façade constituents of case buildings;
- to provide as much energy savings as possible without damaging the historic character and façade constituents of case buildings;
- to select effective insulation materials compatible with case building character;
- to meet TS 825 Thermal Insulation Requirements for the components of buildings' envelopes.

A total of 17 possible energy-efficient retrofit solutions were evaluated considering the five-level assessment criteria introduced by EN 16883: 2017. All retrofit solutions were divided into three risk groups, including high-risk solutions, low-risk solutions and neutral solutions (Table 8).

First, external insulation of external walls and changing doors were eliminated, since they carry a risk for Group 2 buildings according to the heritage value impact assessment. Thus, these solutions were left out of the scope of appropriate solutions for Group 2 buildings.

Five retrofit solutions, the yellow colored boxes shown in Table 8, were specified as low-risk solutions which cause less impact on the buildings' façade characters and appearance while causing change on the buildings' components. The retrofit solutions with low risk were:

- internal insulation of external walls;
- insulation of oriel wall;
- insulation of oriels' ground floor;
- insulation of external floor;
- changing windows.

Seven retrofit solutions were specified as the neutral solutions causing physical change on the buildings' envelopes, but without damaging the historic character of buildings according to the heritage value impact assessment. The neutral retrofit solutions for Group 2 buildings were:

- weather stripping to improve air-tightness of the building envelope;
- insulation of basement floor;
- insulation of ground floor;
- insulation of attic floor;
- insulation of oriel attic floor;
- insulation of oriel roof;
- insulation of pitched roof.

Table 8. Heritage value impact assessment for 17 energy-efficient retrofit solutions of Group 2 buildings (red: high risk; yellow: low risk; white: neutral; gray: no solution).

	Possible Retrofit Solutions	**Group 2** **B1**	**B8**	
Change on building envelope	External insulation of external wall			Eliminated Solutions
	Changing doors			
	Internal insulation of external wall			
	Insulation of oriel wall			
	Insulation of oriel ground floor			
	Insulation of external floor			
	Changing windows			
	Insulation of oriel attic floor			Package 2
	Weather stripping			Package 1
	Insulation of basement floor			
	Insulation of attic floor			
	Insulation of oriel roof			
	Insulation of pitched roof			
	Insulation of ground floor			
Building Operation	Use of oriel as sunspace			Operational Solutions
	Shutter control			
	Nightime ventilation			

Some of the retrofit solutions were grouped under the retrofit packages while some were individually evaluated. The neutral solutions which cause the physical changes on buildings' envelope were included in a package named as Package 1 and separately simulated for Group 2 buildings. Low-risk solutions for Group 2 buildings were not individually performed because of similar reasons to the Group 1 buildings. Unchanged or less changed façades for this group of buildings are principally desired due to their façade characteristics. Low-risk solutions were combined and simulated with the Package 1 for Group 2 buildings. Thus, Package 2 originated from the combination of solutions with low risk and a neutral effect on the heritage value of Group 2 buildings. Furthermore, operational solutions were not grouped in order to observe their individual effects on the buildings' envelopes (Table 9).

Table 9. Determined retrofit solutions and packages for Group 2 Buildings.

Group 2 Buildings.		
Package 1 (Neutral Related to Building Envelope)	**Package 2 (Combination of Neutral and Low-Risk)**	**Individual Operational Solutions (Neutral Related to Building Operation)**
Insulation of oriel attic floor Insulation of basement floor Insulation of attic floor Insulation of oriel roof Insulation of pitched roof Insulation of ground floor	Internal insulation of external wall Insulation of oriel wall Insulation of oriel ground floor Insulation of external floor Changing windows Insulation of oriel attic floor Weather stripping Insulation of basement floor Insulation of attic floor Insulation of oriel roof Insulation of pitched roof Insulation of ground floor	Use of oriel as sunspace Shutter control Nightime ventilation

3.5.3. Assessment of Possible Retrofit Solutions for Group 3 Buildings

The retrofit targets determined for Group 3 buildings were:

- to provide as much as energy savings as possible by implementing the appropriate retrofit solutions;
- to select the retrofit materials compatible with the buildings' envelopes;
- to ensure the buildings' components meet TS 825 Thermal Insulation Requirements after retrofit.

The heritage value impact assessment for Group 3 buildings was not performed, because they consisted of contemporary buildings which did not present any historic character and heritage value. Therefore, a list of 11 possible retrofit solutions was prepared. Then, the retrofit solutions were grouped according to their vertical and horizontal building components. The solutions applied for the vertical building components, i.e., walls, windows and doors, were determined as Package 1. Package 2 consisted of the combination of retrofit solutions applied for both the vertical and horizontal building components. Then, the operational solutions were individually assessed for Group 3 buildings (Table 10). Package 1 included the retrofit solutions which were thought to be preferable in terms of priority and ease of implementation.

Table 10. Determined 11 retrofit solutions and packages for Group 3 buildings.

Group 3 Buildings		
Package 1 (Vertical Components)	**Package 2 (Horizontal Components)**	**Individual Operational Solutions**
External wall insulation changing windows Changing doors	Insulation of attic floor Insulation of flat roof Insulation of pitched roof insulation of external floors Insulation of basement floor Insulatation of ground floor	Shutter control Nightime ventilation

Package 2 aimed to observe the effect of the combined solutions produced for both vertical and horizontal components of Group 3 buildings, except for the operational solutions. Therefore, following specifications on the solutions for horizontal building, components were presented in addition to the above-mentioned specifications about the vertical components within Package 1. When insulating all the floor types for Group 3 buildings, it was considered whether to directly implement insulation materials to the upper level of the existing floor without excavating and then place floor covering material on it.

4. Results

The results of the determined retrofit packages and individual retrofit solutions for each building category, i.e., Group 1, Group 2, and Group 3, are presented in separate subsections. All retrofit proposals were simulated by using DesignBuilder BPS software version 5.2.003 and 5.5.0.012. The comparison among retrofit packages and base case conditions of the buildings are illustrated in the next sections.

4.1. Results of Retrofit Solutions Belonging to Group 1 Buildings (HR)

4.1.1. Results of Retrofit Packages for Group 1 Buildings (HR)

Regarding total energy consumption for heating, the amount of energy saving for Group 1 buildings ranged from 9.0% (Building 15) to 17.89% (Building 19) with Package 1. This rate changed from 34.64% (Building 12) to 60.6% (Building 22) through Package 2 (Table 11). For the total energy consumption for cooling, Package 1 significantly enabled reductions on energy consumption of almost all the buildings. However, there exists an increase in cooling consumption of 25.92% and 41.7% in Building 15 and 21, respectively. The minimum energy saving achieved by Package 1 was 2.45% in Building 12, while the maximum energy saving was 85.87% for Building 22. Package 2 provided a minimum energy saving of 28.11% in Building 15 and a maximum of 91.15% in Building 22, in comparison to the base case of buildings (Table 11).

Table 11. Change rates in annual energy consumption compared to base case of Group 1 buildings through Package 1 and Package 2.

Group 1 Buildings	Package 1 (%)		Package 1 Total (%)	Package 2 (%)		Package 2 Total (%)
	Heating	Cooling		Heating	Cooling	
Building 4	−9.09	−6.74	−8.99	−38.84	−35.24	−38.70
Building 7	−13.31	−18.93	−13.52	−52.00	−66.50	−52.52
Building 12	−11.92	−2.45	−11.71	−34.64	−36.08	−34.67
Building 14	−10.25	−12.38	−10.32	−52.47	−46.65	−52.27
Building 15	−9.00	25.92	−8.12	−41.51	−28.11	−41.17
Building 17–18	−13.12	−3.99	−12.77	−59.68	−30.25	−58.55
Building 19	−17.89	−19.02	−17.92	−43.71	−43.38	−43.70
Building 20	−15.97	−5.31	−15.68	−37.84	−33.61	−37.72
Building 21	−11.19	41.70	−9.38	−60.60	−36.96	−59.79
Building 22	−11.30	−85.87	−31.43	−56.42	−91.15	−65.80

The results of annual energy consumption indicated that the minimum energy saving obtained from Package 1 was 8.12% (Building 15) and the maximum was 31.43% (Building 22). Through Package 2, the energy saving rate increased by a minimum of 34.67% (Building 12) and a maximum of 65.8% (Building 22) in proportion to base case (Table 11).

4.1.2. Results of Operational Solutions for Group 1 Buildings (HR)

According to the results of individual operational solutions, it could be remarked that the night-time ventilation slightly differed from other operational solutions, in terms of providing more energy saving specifically for the cooling season and applicability to all existing windows of Group 1 buildings. The use of oriels as a sunspace and shading control did not completely perform for all case buildings because of the use of the existing shutters and the fact that not all buildings had an oriel. These solutions implemented to the existing building components had close results as compared with the night-time ventilation strategy (Table 12).

Table 12. Change rates in annual energy consumption compared to base case of Group 1 buildings through operational solutions.

Group 1 Buildings	Use of Orielsas a Sunspace (%)			Nighttime Ventilation (%)			Shading Control (%)		
	Heating	Cooling	Total	Heating	Cooling	Total	Heating	Cooling	Total
Building 4	-	-	-	−3.2	−0.9	−3.1	-	-	-
Building 7	−4.0	1.1	−3.8	−4.0	−23.7	−4.7	−3.9	−16.3	−4.4
Building 12	−1.5	−4.2	−1.5	−1.5	−37.6	−2.2	−1.6	−3.1	−1.6
Building 14	−1.6	6.0	−1.4	−1.7	−23.1	−2.4	−1.6	5.5	−1.4
Building 15	-	-	-	−2.8	−37.7	−3.7	-	-	-
Building 17–18	−0.3	8.9	0.1	−0.3	−13.5	−0.8	−0.3	−1.0	−0.3
Building 19	−1.9	4.5	−1.7	−1.9	−28.2	−2.6	−1.9	1.2	−1.8
Building 20	-	-	-	0.0	−0.3	0.0	−2.5	−8.9	−2.6
Building 21	-	-	-	0.7	4.1	0.9	-	-	-
Building 22	-	-	-	0.0	−23.3	−22.5	0.0	−4.8	−21.9

4.2. Results of Retrofit Solutions Belonging to Group 2 Buildings (HNR)

4.2.1. Results of Retrofit Packages for Group 2 Buildings (HNR)

The energy consumption results for heating season indicates that there is a remarkable difference between Package 1 and Package 2. Through Package 2, the highest reduction occurred in Building 8, by 47.34%, and Building 1, by 42.63%. Package 1 provides less energy saving, by 17.56% in Building 1 and 10.06% in Building 8, compared to the base case (Table 13).

Table 13. Change rates in annual energy consumption compared to base case of Group 2 buildings through Package 1 and Package 2.

Group 2 Buildings	Package 1 (%)		Package 1 Total (%)	Package 2 (%)		Package 2 Total (%)
	Heating	Cooling		Heating	Cooling	
Building 1	−17.56	60.13	−15.38	−47.34	48.69	−44.65
Building 8	−10.06	34.99	−9.41	−42.63	−23.98	−42.36

The results of energy consumption for cooling show that Package 1 and Package 2 unexpectedly increased the energy consumption of two buildings while only Package 2 provided a reduction of 23.98% for Building 8. The increase rate was 34.99% for Building 1 and reached 13% for Building 8 through Package 1 (Table 13).

Considering the total annual energy saving rates, there was a significant difference varying from 30% to 35% between Package 1 and Package 2. The maximum saving obtained from Package 2 was 44.65% for Building 1 and 42.36% for Building 8. The minimum energy saving rate was 9.41% for Building 8 and 17.56% for Building 1 through Package 1 (Table 13).

4.2.2. Results of Operational Solutions for Group 2 Buildings (HNR)

Individual operational solutions provided minor energy savings for Group 2 buildings. Nevertheless, these solutions can be considered as favorable since they did not damage on historic buildings' envelopes and appearances, although Group 2 Buildings were not officially registered. Among the individual solutions, the strategy of the use of oriels as a sunspace was conducted for only Building 1. All operational solutions indicated the same amount of saving, i.e., 1.7%, for the heating season, compared with energy consumption for cooling. It can be concluded that the night-time ventilation strategy is more effective for reducing energy for cooling (Table 14).

Table 14. Change rates in annual energy consumption compared to base case of Group 2 buildings through operational Solutions.

Group 2 Buildings	Use of Orielsas a Sunspace (%)			Nighttime Ventilation (%)			Shading Control (%)		
	Heating	Cooling	Total	Heating	Cooling	Total	Heating	Cooling	Total
Building 1	−1.7	2.6	−1.6	−1.7	−19.4	−2.2	−1.7	−20.1	−2.2
Building 8	-	-	-	−2.9	−34.9	−3.4	−2.9	2.0	−2.8

4.3. Results of Retrofit Solutions Belonging to Group 3 Buildings (C)

4.3.1. Results of Retrofit Packages for Group 3 Buildings (C)

Regarding the total energy consumption for heating, both packages revealed significant reductions for most of Group 3 buildings. The highest energy reduction for heating occurred in Building 11, with 67.43%, through Package 2, while the lowest result was in Building 16, with 9.3%, through Package 1 (Table 15).

Table 15. Change rates in annual energy consumption compared to base case of Group 3 buildings through Package 1 and Package 2.

Group 3 Buildings	Package 1 (%)		Package 1 Total (%)	Package 2 (%)		Package 2 Total (%)
	Heating	Cooling		Heating	Cooling	
Building 2	−51.74	−35.14	−50.91	−52.49	−39.01	−51.82
Building 3	−9.31	−13.82	−9.83	−35.13	−72.95	−39.48
Building 5	−26.12	−49.91	−26.88	−27.01	−54.75	−27.90
Building 6	−36.25	−43.70	−36.41	−52.15	−16.40	−51.41
Building 9	−15.50	−41.25	−16.22	−25.29	−46.88	−25.89
Building 10	−18.95	−54.58	−19.90	−43.83	−26.65	−43.37
Building 11	−44.93	−26.32	−44.06	−67.43	−59.27	−67.05
Building 13	−27.56	−40.40	−27.90	−36.14	−45.66	−36.39
Building 16	−9.30	−8.77	−9.26	−45.51	−83.59	−48.42

The energy consumption for cooling also decreased with both packages, yet Package 2 provided higher energy saving rates. The highest reduction occurred in Building 16 (83.59%), through Package 2, while Package 1 resulted in the lowest reduction rate of 8.77%, in Building 16 (Table 15).

Regarding annual energy consumption, although Package 2 enables more energy saving, both retrofit packages provide significant energy conservation. The maximum rate was 67.05% for Building 11, through Package 2, while the minimum was 9.26% in Building 16, through Package 1 (Table 15).

4.3.2. Results of Operational Solutions for Group 3 Buildings (C)

Individual operational solutions create more energy savings compared to other building groups. Both strategies including night-time ventilation and shading control with shutters providing close results for energy consumption for heating and cooling. The use of shutters resulted in higher energy saving rates for Building 2 and 3 with a marked difference. The operation of the night-time ventilation strategy was effective on Building 11 and 13, compared to shading control for cooling season (Table 16).

Table 16. Change rates in annual energy consumption compared to base case of Group 3 buildings through operational solutions.

Group 3 Buildings	Nighttime Ventilation (%)			Shading Control (%)		
	Heating	Cooling	Total	Heating	Cooling	Total
Building 2	−0.9	−46.4	−3.2	−0.9	−60.9	−3.9
Building 3	−30.2	−67.8	−34.5	−30.2	−80.5	−36.0
Building 5	12.3	10.0	12.2	12.3	6.8	12.1
Building 6	−8.9	−14.9	−9.1	−8.9	−14.9	−9.1
Building 9	0.0	12.3	0.3	0.3	−4.8	0.1
Building 10	−0.5	−22.3	−1.0	−0.5	−21.1	−1.0
Building 11	−13.9	−43.7	−15.3	−13.9	−7.9	−13.6
Building 13	−0.3	−33.4	−1.1	−0.3	−4.3	−0.4
Building 16	4.6	3.0	4.5	-	-	-

5. Discussion

5.1. Evaluation among Building Categorizations

For Group 1 buildings, Package 1 (the neutral solutions) provided an average of 15.11% of energy saving, while the highest energy savings was 50.90% obtained from Package 2 (the combination of low risk and neutral solutions). Considering the Group 2 buildings, 11.93% of energy saving was achieved by implementing Package 1 (the neutral solutions) while Package 2 (the combination of low risk and neutral solutions) provided an energy saving of 43.33%. Regarding Group 3 buildings, Package 1 (the retrofit solutions for vertical building components) provided a 30.11% energy saving for Group 3 buildings. Package 2 (the combination of solutions for both vertical and horizontal building components) resulted in 50.90% of the energy saving rate (Table 17).

Table 17. Evaluation of annual energy consumption results among building categories.

Case Buildings	Retrofit Packages (%)		Individual Operational Solutions (%)		
	Package 1	Package 2	Use of Oriels as Sunspace	Nighttime Ventilation	Shading Control
Group 1 Buildings	−15.11	−50.90	−1.45	−4.96	−5.25
Group 2 Buildings	−11.93	−43.33	−4.49	−4.40	−4.35
Group 3 Buildings	−30.11	−45.83	-	−6.81	−6.38

Among all the building categories, Package 2 achieved the maximum energy saving of 50.90%, while the minimum energy saving rate of 11.93% was obtained from Package 1. It was deduced that for all building groups, Package 2 enabled the saving of considerably more energy than Package 1. Only for Group 3 buildings, there occurred a close energy saving result between Package 1 and Package 2, compared to the other building groups (Table 17).

Individual operational solutions provided minor energy savings, in comparison to the solution included in packages for case building groups. Although these individual solutions did not provide as effective energy savings as the packages, they did not cause any changes on buildings' envelopes; therefore, these solutions have an importance in terms of protecting the heritage values and the characteristics of the Group 1 and Group 2 buildings. The night-time ventilation strategy saved the highest energy of 6.81% for the Group 3 buildings. A minimum energy saving rate of 1.45% was obtained from the strategy of the use of oriels as sunspace for Group 1 buildings. Night-time ventilation was the most effective solution in terms of energy saving among individual operational solutions (Table 17).

5.2. Evaluation of All Case Buildings

Out of all case buildings, the maximum energy saving was provided by Package 2, with 48.57%, while the minimum energy saving was obtained from Package 1, with 19.8% (Table 18). Among the individual operational solutions, night-time ventilation and shading control provided similar energy savings. The energy saving rates were 5.2% and 5.4%, for night-time ventilation and shading control, respectively. The use of oriels as sunspace resulted in a minor energy saving rate of 1.5% for all case buildings (Table 19).

Table 18. Evaluation of annual energy consumption results for retrofit packages in all case buildings.

All Case Buildings	Annual Energy Consumption		
	Base Case	Package 1	Package 2
Total (kWh)	506,924	406,568	260,735

Table 19. Evaluation of annual energy consumption results for individual operational solutions in all case buildings.

All Case Buildings	Annual Energy Consumption			
	Base Case	Use of Oriels as Sunspace	Nighttime Ventilation	Shading Control
Total (kWh)	506,924	191,837	480,556	420,493

5.3. Evaluation of Building Groups Based on Energy Classes

In this section, all the building groups were evaluated according to the energy classes for energy consumption. The energy class of the buildings was determined by calculating the annual primary energy consumption per unit occupied floor area. For new and existing buildings, the Energy Performance Regulation on Buildings of Turkey stipulates the preparing of a Building Energy Certificate that includes a classification of energy performance varying between A (the best) and G (the worst). According to the regulation, new buildings are required to have a rating of class C or higher [37]. Although there is no restriction about the energy class of historic buildings, all building groups were included in this evaluation.

Among Group 1 buildings (HR), two base case buildings (Building 14 and 20), three buildings with Package 1 (Building 14, 20 and 21) and seven buildings with Package 2 (Building 4, 7, 14, 17–18, 20, 21, and 22) met the minimum energy class of C and above, according to the regulation. Building 12, 15 and 19 did not meet the minimum energy class of C and above in any cases, before or after retrofit. Package 1 provided the highest change rate on energy class for Building 22 (from F to C), compared to base case. There was no change in energy class for Building 4, 12 and 15 by implementing Package 1. Through Package 2, the highest change rate on energy class occurred in Building 17–18 and 22 (from F to B) compared to the base cases (Table 20).

Among Group 2 buildings (HNR), the energy class results for the base case and all the packages were the same as energy class B for Building 1. For Building 8, the energy classes of both base case and Package 1 were found to be energy class F, which is not acceptable, according to the Energy Performance Regulation on Buildings of Turkey. Through Package 2, it achieves minimum energy class (C) (Table 20).

Table 20. Primary energy consumption and energy classes of the base and retrofitted cases for all case buildings (light green: minimum energy class C; green; energy class B; dark green: energy class A).

Building Groups		Base Case Total (kWh/m^2)	Base Case Energy Class	Package 1 (kWh/m^2)	Package 1 Energy Class	Package 2 (kWh/m^2)	Package 2 Energy Class
GROUP 1	Building 4	215.05	E	195.95	E	132.20	C
	Building 7	202.25	E	174.40	D	94.71	B
	Building 12	278.61	F	246.71	F	181.91	D
	Building 14	143.52	C	128.58	B	68.85	B
	Building 15	281.06	F	261.41	F	166.57	D
	Building 17–18	247.14	F	216.66	E	105.92	B
	Building 19	294.44	G	241.56	F	165.81	D
	Building 20	149.90	C	126.95	B	93.57	B
	Building 21	197.56	E	183.52	D	81.44	B
	Building 22	256.66	F	138.46	C	70.31	B
GROUP 2	Building 1	130.58	B	114.12	B	76.75	B
	Building 8	257.70	F	235.66	F	149.44	C
GROUP 3	Building 2	426.99	G	209.61	C	205.74	C
	Building 3	293.56	E	264.69	D	177.65	B
	Building 5	389.43	F	237.58	C	234.28	C
	Building 6	117.72	B	74.63	B	58.33	A
	Building 9	325.13	E	272.39	D	240.94	D
	Building 10	159.92	C	126.16	B	91.49	B
	Building 11	203.05	D	115.73	B	67.85	A
	Building 13	156.28	C	111.99	B	98.89	B
	Building 16	506.16	G	459.27	G	261.06	D

Among Group 3 buildings (C), the highest change rate in energy class (from G to C) was provided in Building 2 through Package 1. There was no change in the energy class of Building 16 with Package 1. Through Package 2, energy classes of most buildings were class B. The highest change rate occurred in Building 2 (from G to C), followed by Building 3 (from E to B), Building 5 (from F to C), Building 11 (from D to A), Building 16 (from G to D), Building 6 (from B to A), Building 13 (from C to B) and Building 9 (from E to D) (Table 20).

For all building groups, Package 2 provided the highest improvements on energy classes compared to Package 1. Moreover, Group 3 buildings indicated better performance in energy classes in comparison to the other building groups.

5.4. Evaluation of Relationship between Design Parameters and Building Energy Consumption

The numerical analysis was conducted by using Pearson correlation analysis. Seven design parameters, based on the geometric variables of building form, mentioned in the Section 3.2.2, were investigated for each case building to find the most influential parameters on building energy consumption.

The calculated values of parameters belonging to each case building are presented in (Table 21), while the results of Pearson correlation analysis (R values) are presented in Table 22. The outcomes convey that DP1 (total surface area to conditioned volume ratio (S/V)) and DP5 (usable ground floor area (m^2) to conditioned volume (m^3)) are negatively and significantly related to the annual energy consumption of buildings. In other words, buildings that have lower levels of S/V and usable ground floor area (m^2) to conditioned volume (m^3) are likely to have higher annual energy consumption per m^2. P4 (length to depth), DP6 (total usable floor area to conditioned volume) and building DP7 (height to depth), on the other hand, are the variables are positively related to energy consumption, although the correlation is statistically insignificant (Table 22).

Table 21. Numerical analysis results for design parameters.

Case Buildings	Total Annual Energy Consumption (kWh)	DP1	DP2	DP3	DP4	DP5	DP6	DP7
Building 1	18,546.45	0.89	14.83	16.86	2.26	0.18	0.37	1.27
Building 2	6980.19	1.36	10.82	3.48	0.51	0.21	0.21	0.52
Building 3	10,072.96	1.28	12.6	31.55	1.40	0.34	0.34	0.45
Building 4	9750.90	1.51	1.54	7.79	0.57	0.18	0.36	0.78
Building 5	8030.71	1.40	9.17	46.4	0.67	0.29	0.29	0.37
Building 6	32,205.86	0.80	5.58	20.14	0.58	0.14	0.36	0.74
Building 7	27,693.98	1.16	7.08	11.19	1.84	0.25	0.41	1.10
Building 8	25,414.80	1.08	4.25	19.04	0.74	0.16	0.31	0.78
Building 9	6670.72	1.56	4.83	18.86	0.84	0.18	0.36	0.85
Building 10	13,831.17	1.02	7.96	12.88	0.73	0.24	0.38	0.70
Building 11	29,327.03	1.16	12.13	51.91	0.96	0.15	0.45	1.63
Building 12	18,834.18	1.58	6.37	21.11	0.98	0.18	0.38	1.06
Building 13	51,986.99	0.64	5.51	14.63	0.79	0.10	0.31	0.74
Building 14	47,009.47	0.88	3.87	16.66	0.58	0.15	0.49	0.64
Building 15	26,581.31	1.14	3.76	19.84	0.66	0.15	0.29	0.64
Building 16	8538.26	1.96	-	-	2.58	0.40	0.40	1.50
Building 17–18	47,314.48	1.23	8.33	19.02	2.61	0.18	0.34	1.25
Building 19	35,287.91	1.33	6.28	28.3	0.41	0.18	0.36	0.77
Building 20	23,614.83	1.29	5.56	16.85	0.55	0.22	0.51	0.95
Building 21	17,631.81	1.17	3.41	17.33	0.67	0.17	0.34	0.74
Building 22	41,600.29	0.81	11.74	19.9	1.41	0.18	0.37	0.75

Table 22. Results of Pearson coefficient analysis.

Design Parameters	R Value	Relation
DP1	−0.660320 *	Medium
DP2	−0.100082	Very low
DP3	−0.012648	Very low
DP4	0.219320	Very low
DP5	−0.565679 *	Medium
DP6	0.289929	Very low
DP7	0.260149	Low

Note: * r values closest to −1.

5.5. Integrated Approach to Identify Case-Specific Energy-Efficient Solutions for Retrofit Strategy of Larger Scale Historic District

The need for developing retrofit strategy for larger scale case studies was confronted while deciding which buildings could provide the most energy saving within the given time limitations of the project. In cases with insufficient building data, it was required to focus on accessible data derived from building envelope with a quick field survey. This study introduced an integrated approach to identify case-specific energy efficient solutions for a retrofit strategy of a larger scale historic district.

This approach was composed of eight main steps, the approach starting with determination of the most effective design parameters on annual energy consumption of buildings (Table 23). Then, identified parameters were sorted within themselves and 50% of buildings with more energy consumption were chosen. The same building(s) in each identified design parameter were selected. Then, BPS model of the selected buildings was created, and their annual energy consumption was calculated. Energy classes of the buildings, considering primary energy consumption, were defined. Afterwards, the buildings meeting the minimum energy class (C) and above (B and A) were eliminated.

The retrofit solutions/packages were applied to the rest of the BPS model of the building(s). Finally, it was decided whether the buildings met the minimum energy class (C).

Table 23. Integrated approach of this study for retrofit strategy of larger scale historic district.

1	Determination of the design parameters related to annual energy consumption of buildings
2	Identification of the most-related ones among the design parameters
3	Sorting identified parameters within themselves and determination of 50% of buildings consuming more energy
4	Determination of same building(s) in each identified design parameter
5	Creation of determined building(s)' BPS model and calculation of their annual energy consumption
6	Identification of energy classes based on primary energy consumption of the building(s)
7	Elimination of the building(s) that meet minimum energy class (C) and application of retrofit solutions/packages in the rest of building(s)' BPS model
8	Determination of the building(s) that meet minimum energy class (C)

In this research, P1 (total surface area to conditioned volume ratio (S/V)) and P5 (usable ground floor area (m^2) to conditioned volume (m^3)) were determined as the two most influential parameters. The calculated values of these parameters were sorted from minimum to maximum value. Of the buildings with more annual energy consumption per each design parameter, 50% corresponded to the first 11 case buildings, colored grey in Table 24 (a) and (b). Then, the same buildings in both parameters were determined, as shown in blue in Table 24 (a) and (b). This means that the number of case buildings to work on decreased to eight.

Table 24. Sorted and determined case buildings based on (a) DP1 (total surface area to conditioned volume ratio (S/V)) and (b) DP5 (usable ground floor area (m^2) to conditioned volume (m^3) ratio) (grey: 50% of case buildings; blue: same buildings in both parameters).

Case Buildings	DP1	Case Buildings	DP5
Building 13	**0.64**	**Building 13**	**0.10**
Building 6	**0.80**	**Building 6**	**0.14**
Building 22	0.81	**Building 15**	**0.15**
Building 14	**0.88**	**Building 11**	**0.15**
Building 1	**0.89**	**Building 14**	**0.15**
Building 10	1.02	**Building 8**	**0.16**
Building 8	**1.08**	**Building 21**	**0.17**
Building 15	**1.14**	Building 9	0.18
Building 7	1.16	Building 4	0.18
Building 11	**1.16**	**Building 1**	**0.18**
Building 21	**1.17**	Building 12	0.18
Building 17–18	1.23	Building 22	0.18
Building 3	1.28	Building 17–18	0.18
Building 20	1.29	Building 19	0.18
Building 19	1.33	Building 2	0.21
Building 2	1.36	Building 20	0.22
Building 5	1.40	Building 10	0.24
Building 4	1.51	Building 7	0.25
Building 9	1.56	Building 5	0.29
Building 12	1.58	Building 3	0.34
Building 16	1.96	Building 16	0.40

The energy classes of the identified eight buildings, based on primary energy consumption, are presented. The buildings with minimum energy class (C) and above, i.e., Building 1 (HNR), 6 (C) and 14 (HR), in base cases were eliminated since they already met the requirements of the Energy Performance Regulation on Buildings of Turkey.

Finally, the remaining four buildings, including Building 8 (HNR), 11 (C), 15 (HR) and 21 (HR), were evaluated according to the energy class change of the retrofit packages. Building 15 (HR) was disregarded in the evaluation process, because both Package 1 and Package 2 did not cause any change in the energy class of this building. Consequently, three buildings (Building 8 (HNR), 11 (C) and 21 (HR)), that did not meet minimum energy class (C) were determined as the buildings which could be initially retrofitted (Table 25).

Table 25. Energy classes of identified eight buildings based on primary energy consumption (blue: buildings which do not meet minimum class (C)).

	Base Case Energy Class	**Package 1 Energy Class**	**Package 2 Energy Class**
Building 13	C	B	B
Building 6	B	B	A
Building 14	C	B	B
Building 1	B	B	B
Building 8	F	F	C
Building 15	F	F	D
Building 11	D	B	A
Building 21	E	D	B

Package 1 solutions provided an improvement for only Building 11 (C), from D to B. Package 2 solutions provided an improvement for Building 8 (HNR) from F to C and for Building 21 (HR) from E to B and for Building 11 (C) from D to A (Table 25).

Three buildings, which can initially be retrofitted, represent each building group: Building 21 (HR) belonged to officially registered historic buildings (Group 1), Building 8 (HNR) belonged to non-registered but historic buildings (Group 2) and Building 11 (C) belonged to contemporary buildings (Group 3) (Figure 8). Building 8 (HNR) and 21 (HR) were the second most energy saving buildings in their own groups, through Package 2. Package 1 did not provide effective energy saving results for Building 8 (HNR) and 21 (HR). Building 11 (C) had the second most energy saving potential, through Package 1, and the most energy saving potential by Package 2 among Group 3 Buildings.

(a) (b) (c)

Figure 8. (**a**) Building 21(HR) (9% energy saving by Package 1; 60% energy saving by Package 2), (**b**) Building 8 (HNR) (9% energy saving by Package 1; 42% energy saving by Package 2) and (**c**) Building 11 (C) (44% energy saving by Package 1; 67% energy saving by Package 2) where retrofit solutions can be applied initially.

6. Conclusions

This paper presents the study at the urban neighborhood, consisting of a total of 22 historic and contemporary buildings with residential and commercial use. It introduces an integrated approach to retrofit buildings in the larger scale historic urban fabric. Improving the energy performance of the buildings' envelopes by proposing energy-efficient retrofit solutions in different impact categories, while protecting and maintaining the heritage value and architectural character of historic buildings, was the primary concern.

As a consequence, following conclusions can be derived:

1. This study indicates the evidence for the possibility of decreasing energy consumption on a neighborhood scale without extensive data collection and in-depth energy audits.
2. The methodology of the research is applied to the historic fabric located in the Mediterranean climate. It is developed as the distinctive roadmap for a rapid reaction required by many historic cities under the thread of rapid transformation and degradation. Therefore, it combines quick survey analysis and statistical assessment with the BPS tool to decide the energy-efficient solutions providing the most energy saving over a short time.
3. There is an ongoing argument between conservation principles and an energy-efficient approach for historic buildings in the restoration practice and previous literature. Proposing energy-efficient retrofit solutions, especially for officially registered buildings, is a major subject that needs to act with deliberation.
4. With respect to conservation principles, a minimum level of intervention is always expected in historic buildings. Accordingly, retrofit solutions should be determined which do not require intervention and/or require minimum intervention for protecting heritage value of buildings.
5. Such interventions which cause changes to building constructions and interior spaces should be considered in detail by the reciprocal communication of architectural restoration and energy conservation specialists, and multifaceted investigation of previous experiences and research.
6. Each historic building necessitates a case-specific approach when the energy-efficient retrofit is the major subject. Each solution may not be appropriate for each building; in other words, the generalization of solutions may inevitably cause conservation risks or energy losses. For instance, a low-risk solution, i.e., internal insulation of external wall, for a historic building may not have any risk at all for another historic building.
7. The implementation of current energy performance regulations for existing and new buildings is a matter of debate for historic buildings. When it comes to energy-efficient improvements, it is controversial whether historic buildings can be treated as other existing buildings or whether they are to be given a specific thermal target, such as certain U-value. In the case that there is no predefined calculation procedure about historic buildings in the Energy Performance Regulation on Buildings of Turkey, this study draws attention to whether the applicability of the TS 825 Thermal Insulation Requirements for Buildings, in which the specific thermal requirements are defined for building components of envelope per each climatic zone, is possible for historic buildings, or not.
8. This study points out the necessity of using the procedure on how to decide and assess energy-efficient solutions for historic buildings. Therefore, the study utilized the assessment criteria and scale of EN 16883: 2017. This standard provided the guidance on sustainability and improvement of the energy performance of historic buildings while respecting their heritage value. It presents a systematic procedure which enables the user to find the best solution for historic buildings with a case by case approach.

This study provides information regarding different retrofit approaches, i.e., the energy-efficient retrofitting of buildings from different categorizations in the same neighborhood. Overall consideration in determining the possible energy-efficient retrofit solutions for urban building stock, hosting both historic and contemporary buildings, enables its usability, in terms of bringing different retrofit approaches together. This contributes to the current literature by developing an integrated approach about how to decide retrofit solutions at a neighborhood scale, consisting of both historic and contemporary buildings, via quick survey analysis without extensive data collection. It points out the retrofit strategies are characterized for the representative neighborhood so that they may be extrapolated to wider scale urban historic fabric of that particular city.

On the other hand, this research indicates the significance of determining case-specific retrofit packages. The findings related to the retrofit solutions and their interpretation cannot be generalized for other studies. However, the approach of the study can serve as a model for historic building stock in the Mediterranean climate, i.e., the determination process of energy-efficient retrofit solutions and packages within several retrofit strategies. Nevertheless, the number and type of retrofit solutions and packages differ in other studies, since historic buildings have different historic and architectural characteristics depending on cultural, social and geographical facts.

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Abbreviations

BPS	building performance simulation;
ECM	energy conservation measures;
EE	energy efficiency;
EPBD	Energy Performance Building Directive;
TC	thermal comfort;
ENI	environmental impact;
ECI	economic impact;
HV	heritage value;
EIW	external insulation of walls;
IIW	internal insulation of walls;
CWI	cavity wall insulation;
IF	insulation of floors;
IR	insulation of roofs;
IAF	insulation of attic floors;
WS	weather stripping;
RRWD	repairing or replacing of windows and doors;
IS	improving shutters;
IHVAC	improving HVAC systems;
IEA	improving of electrical appliances;
IRES	integration of renewable energy systems;
DH	District Heating.

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