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Retrofit Analysis of a Historical Building in an Architectural Constrained Area: A Case Study in Rome, Italy

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Abstract: A significant portion of Europe's historical buildings have significant potential for energy efficiency. Social policy is typically opposed to energy retrofits because it is concerned about damaging historical or cultural sites. Contrarily, there are several approaches to energy efficiency that may be used with historic structures while also retaining the region's architectural constraints. The findings of this study demonstrate that historical structures, which are typically not targets of energy efficiency technology because of architectural constraints on the building or in the neighbourhood, may also achieve a meaningful decrease in energy usage and GHG emissions. The significant energy-saving capability of this type of building is emphasized in the historical structure taken into consideration. The historical building object of the present study was built in the beginning of the 1900s and it was selected by the Ministry of Culture for energy efficiency improvements.

Keywords: historical building; energy efficiency measures; energy retrofit

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1. Introduction

One-third of the world's greenhouse gas (GHG) emissions come from the construction industry, which is one of the biggest contributors to global warming [1]. Global efforts have been made to design new net-zero energy buildings (nZEBs) [2] and to increase the energy efficiency of existing buildings [3] in order to counteract the climate changes brought on by GHG emissions that can affect outdoor air thermal conditions [4] and increase air pollutant levels in urban areas [5]. These factors have increased the focus of researchers on the topics of reducing energy consumption in buildings [6], analysing outdoor air temperature variations in an urban context [7] and assessing mitigation techniques of the urban heat island phenomenon [8]. Since they make up the majority of the building stock and are lacking in fundamental energy efficiency components, retrofitting existing buildings offers significant energy efficiency potential in comparison to new buildings built as nZEBs [9]. Numerous studies on the best guidelines and methods for conducting energy efficiency retrofits for individual [10] and stocks [11] of existing buildings can be found in the literature. These studies are frequently motivated by initiatives taken by the majority of countries to achieve carbon neutrality for their economies. However, historical structures are excluded from energy-saving initiatives in order to preserve their significance to architectural history. Retrofitting historic buildings used to be considered a possible danger to their worth, but that is changing now. Furthermore, several studies have found that rehabilitated historic buildings in Europe—the majority of them in Italy, followed by the United Kingdom, Spain [12], and China [13]—have significantly improved their energy efficiency. Finding a balance between energy efficiency and thermal comfort while also protecting cultural property is essential for upgrading historic structures. For instance, adding outside wall insulation is not an option since it alters the aesthetic character, but updating inside energy systems, such as lighting fixtures and appliances, is completely compatible. Additionally, installing building-integrated solar photovoltaic systems is feasible in the majority of situations and merits serious consideration [14]. Previous studies offered system methods [15] and assessed a number of retrofitting options, including energy efficiency measures relating to envelopes [16], heating, ventilating, and air conditioning (HVAC) systems [17], a combination of both envelope and HVAC systems [18], and occupant behaviour [19]. For instance, Ascione et al. [20] used experimental and numerical assessments of an Italian administrative building to establish a multi-criteria strategy for energy retrofits of ancient structures. A number of energy-efficiency methods were assessed in the study, including wall thermal insulation, air leakage, setpoint management, window glazing, and heating systems. The study's findings indicated that energy retrofits might cut the building's principal energy usage by 20%. In a protected residential complex in London, Ben and Steamers [19] investigated the advantages of energy retrofits using both physical and behavioural treatments. The research presented three potential retrofitting levels, including capital, cost, and payback period-based energy efficiency enhancements of HVAC and envelope systems. According to the investigation, behavioural modifications create significant prospects for energy savings (62–86%) that sometimes even outweigh physical advancements in energy efficiency.

1.1. Architectural Conservation and Heritage Building Refurbishment

Architectural heritage preservation is no longer a novel idea. In over 200 years, thoughts and tactics have undergone a significant evolution, with local variations, but a global focus on large interventions that go beyond maintenance and necessitate choices based on a profound grasp of values. The validity of restoration and the definition of authenticity are hotly contested topics. International and national charters provide excellent direction but are frequently built on extremely detailed pronouncements that compromise opposing views. In addition to these concerns, there is also the efficacy of procedures that appear to be focused on completing significant tasks quickly, frequently without preventive and follow-up measures. To offer ongoing care and reduce hazards, several processes are put into place in diverse circumstances. For instance, it is customary in England to have technicians evaluate churches every five years [21]. A multinational movement created preventative conservation for museums, establishing agreed principles with a solid scientific foundation [22]. In The Netherlands, the custom of routine inspections is a well-defined paradigm [23] that was further extended in Belgium [24].

A number of studies have examined potential energy efficiency upgrades for historic buildings in urban settings. The energy retrofit potential of an urban community that was severely damaged by the 2009 earthquake in Italy was examined by De Berardinis et al. [15]. Based on a case-by-case approach, the research suggested several energy-efficient alternatives to renovate the masonry structures, attaining 50% increases in energy efficiency. The adaptive reuse of historic buildings in metropolitan areas and communities is another strategy for preservation. Since it prevents destruction and reconstruction, the adaptive reuse of buildings to fit contemporary demands is really sustainable. The adaptive reuse of historic buildings as hotels and guesthouses offers environmental, economic, and social advantages, in addition to its advantage in encouraging tourism for the communities. By keeping these historic treasures from deteriorating and being demolished, it provides structures with a fresh lease on life. There are several examples of historical structures being used in new ways to suit various climes and purposes [12]. Making them into hotels is one of the effective applications of the adaptive reuse of historic sites. As an illustration, Tagliabue et al. [25] thought of converting a rural historic neighborhood into "diffused hotels". In order to protect historic cities, diffused hotels, which consist of spatially dispersed buildings and spaces, are a frequent concept in Italy. According to the data, passive measures and the installation of heat pumps in place of conventional HVAC systems resulted in 76% savings in yearly energy use. Additionally, the installation of on-site PV systems enabled the renovated hotel to achieve net-zero energy.

Applying an acceptable renovation plan to older structures is more difficult, particularly in Italy, where regulations surrounding these buildings' "protected status" make it challenging to make plans into reality. Consequently, academic and professional discussions remain open in the disciplines of preservation, reconstruction, integrated renovation, and redevelopment since there are many issues that need to be taken into account and resolved. This is especially true in Italy, where energy retrofit actions are frequently concentrated on modern buildings.

Reductions in energy usage in housing applications have been largely attributed to the adoption of Italian energy policies, laws, and the steady lowering of the necessary energy required. Old buildings and, generally, all structures found in historic city centers are now not included in the attainment of minimal energy needs following the deployment of energy retrofit measures. Additionally, the retrofit action application for residential structures is costly, optional, and the result of irregular choice, resulting in significant energy use. Therefore, it appears to be a very challenging task to energy renovate historical buildings when considering the alignment of rules, technical, energy, and economic viability.

Many studies on historical building refurbishment have employed a broad variety of building retrofitting strategies, focusing on decreasing energy usage [26] and smart techniques [27]. Arumägi et al. [28] studied different insulation measures, HVAC solutions, and energy sources to achieve a 20–65% reduction in primary energy, also considering that for historic buildings, the renovation solutions can be problematic due to the need to preserve cultural and architectural values. Galatioto et al. [29] developed a case study modeled in four distinct Italian cities with varying climate conditions: Rome, Milan, Cagliari, and Palermo. Eight retrofitting solutions, including window upgrades and building envelop insulation, were simulated for each scenario in Energy Plus. The findings showed that a mix of retrofitting solutions can reduce energy use by up to 30%. To protect a building's authenticity and, at the same time, increase interior thermal comfort, it is still difficult to specify and implement a variety of suitable building retrofitting solutions for historical building repairs. Additionally, from the standpoint of residents, their choices on building upgrades go beyond possible energy savings and the accompanying cost–benefit analysis. If building remodeling improves the thermal comfort and living environment within, people are more likely to be inspired to do so. Throughout this perspective, a variety of "passive refurbishment methods" [30] are outlined with an emphasis on enhancing the thermal efficiency of existing facades via the installation of additional thermal mass to the inner walls, window upgrades, and improved water resistance, among other things. Recent years have seen important advancements in the creation of novel materials (including aerogel-based coatings [31] and vacuum insulation panels [32]), whose efficiency is extremely beneficial in building retrofitting. The energy-saving capability of installing vacuum insulation panels (VIP) onto the outer walls of a one-story structure in a cold environment was assessed mathematically and experimentally by Biswas et al. [33].

1.2. Italian Energy Retrofit Architectural Heritage Regulation

Numerous legislations, plans, national and municipal guidelines, and other documents dealing explicitly with the preservation of architectural heritage have been developed in Italy. The two fundamental protection laws in Italy, Law 1089 [34] for objects of artistic and historical interest and Act 1497 "Protection of Natural Beauty" [35], which were both adopted in 1939, were revised and updated in legislative Decree 490/1999, the "Consolidated Laws in the Field of Cultural and Environmental Heritage" [36]. According to this standard, restoration of a work is described as an action taken "to guarantee the preservation and protection of its cultural values as well as to retain the integrity of the material". Legislative Decree 42/2004, often known as the "Code of Cultural Heritage and Landscape", is the current framework law for cultural heritage [37].

Buildings owned by the state, regions, other local governments, as well as any other public body or institution, and non-profit private legal entities that present artistic, historical, archaeological, or ethnoanthropological values are cultural assets by default and are subject to "monumental" constrains, i.e., they are "historic" buildings "ope legis" if they are just more than 70 years old, as declared by the Law 106/2001 [38]. Similar buildings owned by different legal entities may only be considered "historic" after a "Declaration of Cultural Interest", which is a process that can legally acknowledge the historic and cultural significance of a particular property. As a result, these buildings must meet the necessary protection standards. In the opposite situation, a default historic structure may be declassified to merely be an old existing building by a process called "Verification of cultural interest" that allows for a detailed evaluation of its aesthetic and historical significance. If this value is positive, the building will always be subject to protection; if it is negative, the building will no longer be subject to protection since it is just too old. A government-specific agency known as "Soprintendenza" is in charge of both this procedure and all other permits on protected structures (Superintendence). Any retrofitting action for such structures must first receive approval from the Superintendence for Architectural Heritage.

Despite the fact that there are several technologies for energy retrofitting in existing buildings accessible today [39], many of these solutions cannot be implemented if preservation difficulties are taken into account [40–42]. In addition, despite the large number of CEN standards by the European Committee for Standardization [43] aimed at defining methodologies for energy performance calculations in new and existing buildings, no standards or methodologies have been delivered to date in order to define the intervention boundaries (allowed materials, allowed techniques) or clarify the allowable retrofitting methodologies for historical buildings [44]. There are no general guidelines to define all the intermediate cases (rehabilitation, restoration, etc.), nor are there any recommendations for the most compatible energy retrofitting technologies in Italy, where the competent authority must decide whether or not a historic building may undergo a full or partial renovation.

In Italy, the implementation of Directive 2002/91/EC [45] on the energy performance of buildings is governed by Legislative Decree No. 192 of 19 August 2005 [46], as revised by Law 90/2013 [47] in light of the adoption of Directive 2010/31/EU [48]. If the Superintendence for Architectural and Landscape Heritage issues a negative opinion regarding the feasibility of undergoing any renovations without impairing their character or appearance, it is possible to find in the regulation that historic buildings must comply with European requirements limited to energy certification and operation, maintenance, and inspection of technical installations. For these reasons, the Italian authorities must authorize any retrofitting theory for a historical structure.

1.3. Energy Numerical Model Approaches

Recently, a variety of applications have become accessible for assessing the energy efficiency of buildings. These devices fall into three categories: static, semi-dynamic, and dynamic. Simple methods that just take a few things into account include stationary and semi-dynamic approaches. They are mainly concerned with the assessment of a building's performance under ordinary circumstances of usage, and often, the datasets are standard references from national databases. Outcomes using static tools are limited because they ignore both the thermal inertia of the materials and the cyclical trend of temperature. Semi-dynamic systems are capable of doing this, but they call for streamlined inputs for building descriptions and meteorological information. On the other hand, dynamic simulation tools can precisely assess all variables, but they require specific datasets for weather parameters and building characteristics. Due to their sophistication, these technologies can generate more reliable analyses, and they are more flexible, making them more suitable for simulating old buildings. According to a recent study [49], the dynamic modeling of ancient structures yields superior findings to other techniques when evaluating their energy performance.

An important factor in using the sophisticated capabilities of the tool in order to reflect the real scenario as exactly as possible and to be a trustworthy way to recommend retrofitting solutions is to utilize such software in combination with climatic measurements to achieve proper calibration of the simulation model. A calibration process can be particularly difficult for ancient buildings, especially when construction materials are not exactly understood, and structures of various dates are layered on top of one another. Therefore, precise research of the building's construction history is necessary for the use of dynamic simulations of historic buildings.

1.4. Multi-Criteria Energy Retrofitting

Researchers have examined a number of multi-criteria retrofitting evaluation techniques [50], concentrating on the main energy savings and economic analysis [51]. Qu et al. [52] presented a novel energy performance certification (EPC)-related holistic building retrofitting approach for a Norwegian apartment block built in the 1980s. Zheng et al. [53] proposed a technoeconomic risk decision-making methodology (TERDMM) based on the Monte Carlo (MC) simulation that can support risk-conscious decision making by explicitly quantifying risks. Ciulla et al. [54] investigated the most common retrofitting solutions used in four different Italian cities, focusing on the energy performance of historical building envelopes. Rodrigues et al. [55] conducted an energy-saving and life cycle study on several passive building refurbishment solutions to examine the exchange between the expense of the refurbishment and its effectiveness. The researchers came to the conclusion that life cycle cost savings of about 8–32% is feasible. To explore the thermal efficiency gains of building renovation methods, such as increased insulation for outer walls and roofs, water resistance, and window replacement, Wang et al. [56] suggested a multi-objective optimization technique. The findings of the improvement suggested that an 86.7% annual energy reduction might be made with a 63% increase in thermal comfort.

1.5. Aim of this Study

As shown in the above literature, different types of methods were developed in order to simulate the energy retrofitting of historical buildings. Researchers are often focused on passive technologies, and the aims of papers are on energy saving and thermal comfort evaluation. In some cases, there is the possibility to bring energy improvements to thermal plants with passive strategies. Nowadays, the best energy retrofitting solution cannot be only focused on the reduction in energy consumption, but there is the necessity to pay attention to greenhouse gas emissions and financial feasibility aspects. For these reasons, the aim of this study is to apply a methodology able to investigate retrofitting solutions for historical buildings through a numerical model able to [49] simulate, optimize, and assess the performance of conventional energy saving measurements and/or renewable energy systems, with decision making on technical, economic, and environmental analyses. This model was developed using the RETScreen Clean Energy Project Analysis Software named RETScreen Expert 8 that is able to identify the feasibility of energy models with a simplified energy model that can be used to easy implement different types of energy system combinations.

A significant portion of the historical buildings that make up Europe's built heritage have a significant capacity for energy savings. Social policy is typically opposed to energy retrofits because it is concerned about damaging archaeological or cultural sites. Contrarily, there are a variety of approaches to energy efficiency that may be used with historic structures while also retaining the region's architectural constraints. This study's objective is to evaluate the viability of retrofitting a historic structure located in an area with limited architectural options by examining the technical, economic, budgetary, and environmental viability of each retrofitting plan.

2. Materials and Methods

2.1. Methodology

The aim of this study is to focus on the potential retrofitting options for a historical building placed in an architectural constrained area. Energy efficiency strategies are studied with a technical, economic, financial, and environmental point of view, with the aim of finding the most suitable strategy.

This study starts by developing a numerical model to evaluate the different types of energy used in the building. The numerical model was implemented with the RETScreen Expert tool [57] that allows for the comparation among different system configurations from an energy, environmental, and financial point of view, with an analysis of investment, operation, and maintenance costs that allows for the determination of the economic benefit of intervention. There are many software tools for economic analyses of renewable-energy systems, including TRNSYS and HOMER. These tools are also used for system design optimization. HOMER is focused on electrical but does not take into account thermal systems. RETScreen is used for both electrical and thermal system design, and it is a proper tool for prefeasibility and feasibility studies [58].

The RETScreen tool is able to assess a comprehensive feasibility analysis on the technical, economic, risk, sensitivity, and environmental aspects of a retrofitting solution, either with passive or active technologies for buildings. Furthermore, is it possible to simulate, optimize, and assess the performance of conventional energy saving measurements and/or renewable energy systems, with decision making on technical, economic, and environmental analyses. The retrofitting solution effects can also be immediately evaluated separately or aggregated with a significant reduction in the time cost of energy retrofitting decision making. Furthermore, the RETScreen tool was also chosen because it is quite easy to use compared to other commercial software, and it can be used by technicians to easily access the best retrofitting strategy with a contemporary analysis of energy, financial, and environmental aspects.

The RETScreen Clean Energy Project Analysis Software (RETScreen) is a software able to identify the feasibility of energy models (including renewable energy systems or high-performance systems) and includes tools to assess the energy efficiency. The software allows for the modelling of any power plant for real estate, providing output data useful for a technical, economic, and environmental analysis for an investment in a 'clean energy' project or cogeneration, as in this case. The calculation model was developed by the Canadian Government cooperating with other governments with the technical support of an extensive network of industries, institutions, and academia experts.

The energy model is calibrated using the analysis of bills for one year. Next, several energy retrofitting measures are investigated to reduce the energy consumption of the building. These were chosen taking into account the historical behaviour of the building and the surrounding area in order to avoid measures that may degrade the architectural value and disturb the visual character.

2.2. Case Study

The building is located near the historical city centre of Rome at the location 41°53′19.0″ N 12°31′04.7″ E, placed at an altitude of 48 m above the sea level. The place is an important archaeological area; the buildings and ruins were built in the 3rd and 4th centuries AD. The relatively recent two buildings in the area, in which one of them is the object of the present study, were built in the beginning of the 1900s, and they were used as a military barracks. Aerial views of the construction are shown in Figure 1, while Figure 2 shows the 3D view and photography of the building.

The historical building is approximately 27,031 m^3 in volume, and an overall plant of about 7201 m^2 is allocated on six levels, composed of three floors and three mezzanine floors that do not cover the plant of a normal floor (see Figure 3).

The historical building taken into account was redeveloped in 2007, and it is now used as the head office of the Directorate General for Live Entertainment and the Directorate for Cinema of the Ministry of Culture. The building is used as an office, but there are some meeting rooms and places used for cinema or a restaurant.

Figure 1. Aerial view of the archaeological area of the historical building.

Figure 2. Three-dimensional view of the historical building.

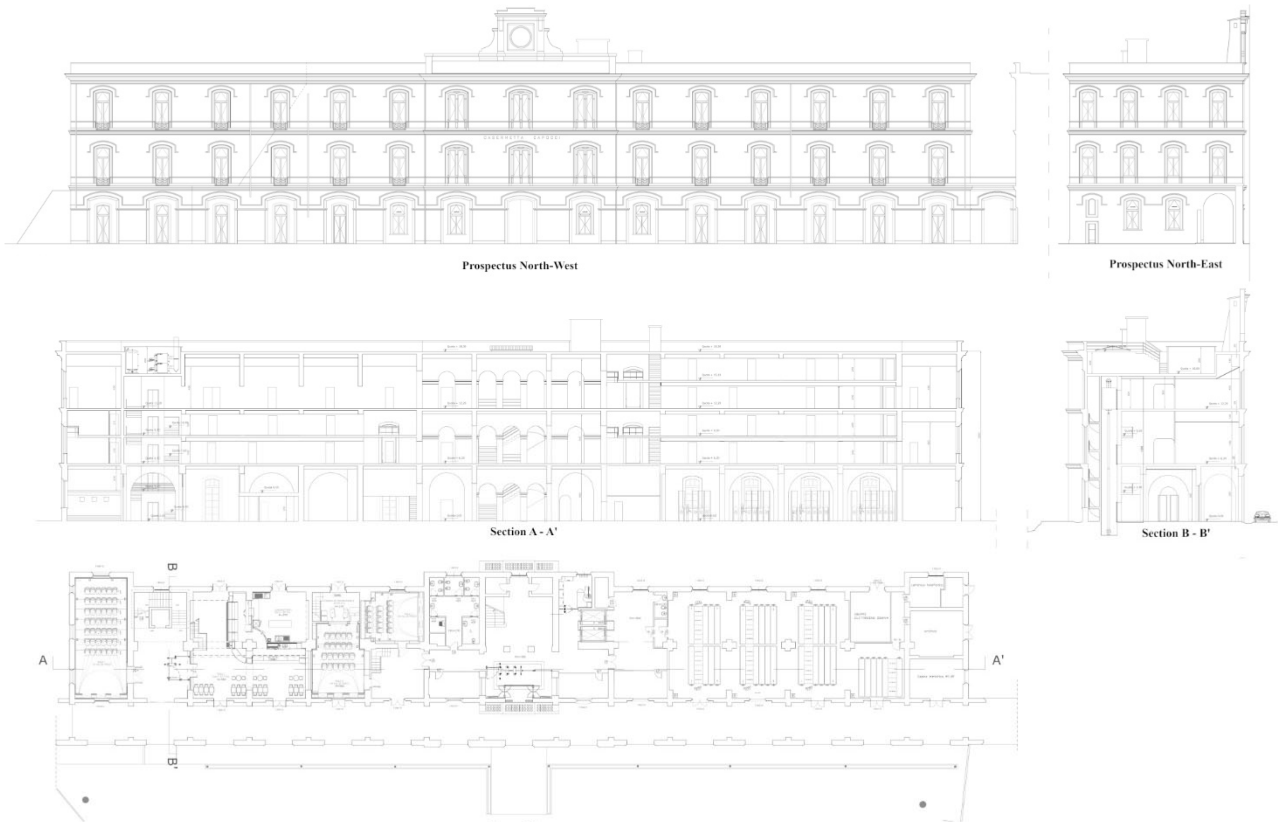


Figure 3. From top to bottom: north-western and north-eastern façades; vertical section A–A′ and B–B′; horizontal section of an example floor (ground floor).

2.3. Energy Efficiency Strategies

In the present section, the various energy efficiency strategies of the case study are shown.

2.3.1. External Wall

The external building walls have a thickness from 50 to 60 cm and are composed of brick with an average calculated transmittance of 1.045 W/m^2 K with a stratigraphy composed of plaster–brick–plaster. These walls do not have the possibility to introduce insulation on the external surfaces in order to avoid the degradation of the architectural and historical values of the facade. For this reason, a thermal insulation paint on the interior with a conductibility of 0.08 W/m K was used, with a final thickness, after two hands of painting, of 0.6 mm. This strategy induces a slight reduction in the thermal transmittance of up to 1 W/m^2 K.

2.3.2. Sun Protection Film

The existing windows are a 4/9/4 type, in which between the two 4 mm glasses, is an interspace of air of 9 mm. The calculated thermal transmittance is about 3.725 W/m^2 K with a g-value of 0.75. A sun protection film, which allows for a reduction in the g-value of up to 0.36, was placed on the windows.

The reflective films are made up of layers of transparent polyester and aluminium. These materials and their combination used in these reflective films can reduce up to 70% of the heat entering the rooms, bringing lower indoor air temperatures, which lead to lower cooling demands.

2.3.3. Roof Insulating

The roof could be retrofitted by the introduction of polyurethane-insulated panels, with a thickness of 5 cm, that can reduce the calculated thermal transmittance from 1.515 W/m^2 K to 0 W/m^2 K.

2.3.4. Optimization of the Thermal Plant Management

The actual HVAC system leads to the same air conditions in all the office rooms of the building with no diversification for the different types of room exposures. As a matter of fact, the building is isolated and benefits from all 4 exposures. In this case, during the summer, there is the possibility that the solar radiation entering from the windows may drastically change the indoor air temperatures. For this reason, the office users often open the windows, even if the thermal plant is switched on.

The problem of air temperature increases in the rooms due to the solar radiation entering from the windows was reduced by the adoption of sun protection films, as described in Section 2.3.2. Furthermore, the reliability of the cooling system was reached by the adoption of new high-efficiency cooling machines as described in Section 2.3.6. In this context, in order to avoid the consuetude of opening the windows in the rooms and keeping the thermal plant switched on, a system was implemented that switches off the plant whenever a window is opened.

2.3.5. Revamping and Optimization of Lighting Management

In the building, there are fluorescent lamps with an average power of 8.076 W/m^2 are installed for each m^2 of surface. The adoption of LED lamps and the use of twilight sensors in common areas and movement sensors inside toilets can reduce the average power installed for each m^2 of surface up to 4.82 W/m^2.

2.3.6. High-Efficiency Cooling Plant

The actual cooling machine has an efficiency of 2.87 that was improved with the adoption of a high-efficiency one that has an efficiency of 3.5.

2.3.7. PV

It is usually difficult to introduce photovoltaic technology without degradation of the architectural values in historical buildings. For this reason, the PVs were placed on the terrace of the last floor, and particular PV technology was used that has a colour similar to the ground of the terrace, bringing a similar visual from the roof. Furthermore, in order to avoid the visual effects of the photovoltaic planes from other buildings taller than the historical building, the PVs were placed with an inclination of 10° and in a pitched configuration.

The PVs, due to their particular colour, have an efficiency of 16.74%, and half were placed with an exposure to the west and the other half to the east. The total PV surface area installed is 468 m^2, with a total peak power of 78.4 kW.

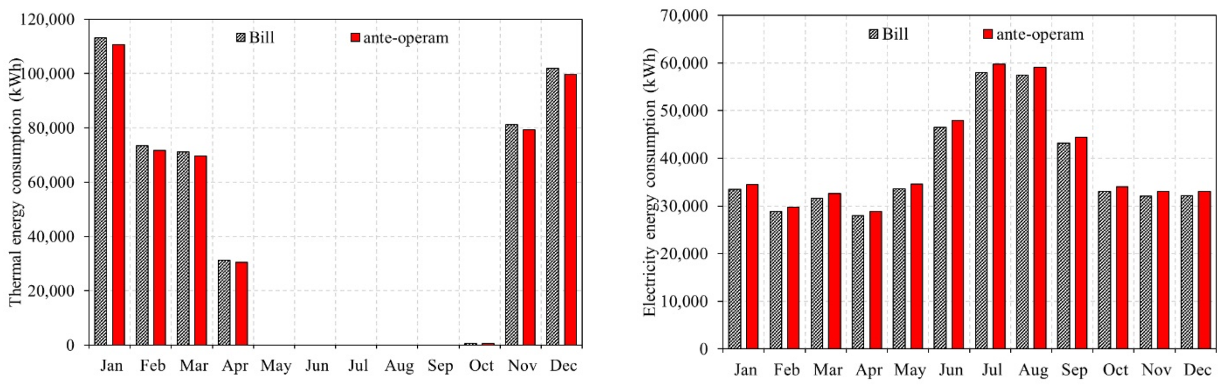
3. Results and Discussions

3.1. Model Calibration

The simulation analysis was conducted with the RETScreen Expert 8 tool, and it was calibrated with readings from the bill of the thermal and electricity energy consumption. The numerical model was implemented taking into account the characteristics of the envelope and the plants used for heating, cooling, lighting, and all the electrical equipment used inside the building. Furthermore, information regarding the occupancy profile was considered in order to setup the power of the plants and to consider the thermal internal gains.

The calibration consists of a comparison of the annual heating, cooling, and electrical demand simulated with the numerical model with the data taken from the bills. In order to minimize the discrepancies between the observed and simulated data, we varied the gains in the numerical model. For the calibration of the electrical demand, considering that, in most of the cases, it is not possible to accurately quantify the amount of electrical equipment, we introduced in the numerical model more or less electrical equipment. About the heating and cooling demand, the calibration was focused on the variation of thermal gains. It is worthwhile to notice that the introduction of thermal gains can vary the cooling demand that brings a variation in the electricity demand due to the use chillers that work with this kind of energy. For these reasons, the calibration method consists of an iterative process in order to minimize the differences in the numerical, thermal, and electrical demand and the readings from the bills.

In the case study, a calibration with a discrepancy in the annual thermal and electricity consumption was achieved; they are, respectively, −2.2% and +3.0%. In particular, in Figure 4, the comparison of the bill and the ante-operam scenario that corresponds to the actual situation of the building is shown.

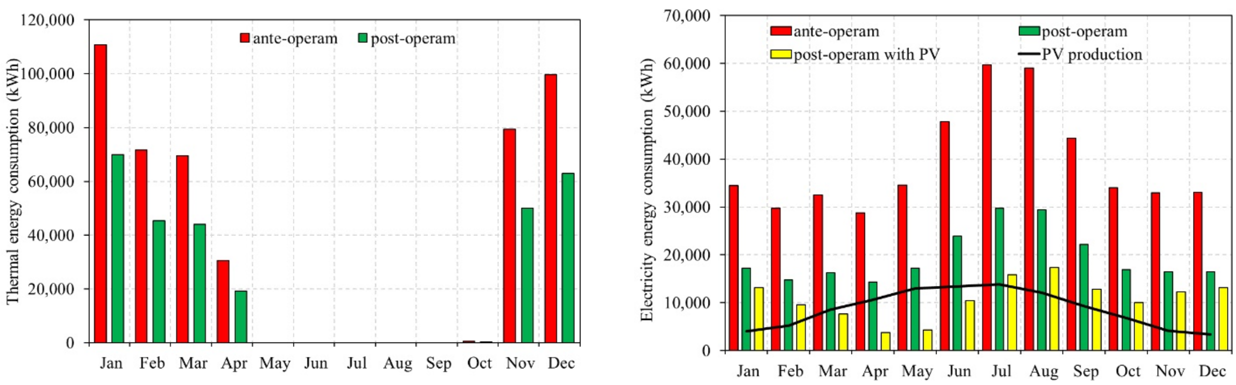


(**a**) (**b**)

Figure 4. Comparison between the bill readings and the simulated energy consumption of (**a**) thermal and (**b**) electricity.

3.2. Retrofitting Scenario Analysis

The post-operam scenario was conducted with all the energy efficiency strategies mentioned in Section 2.3. Figure 5 shows the comparison between the ante-operam and post-operam scenario. In particular, Figure 5b shows the post-operam scenario with and without the PV production.



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

Figure 5. Comparison between ante-operam and post-operam energy consumption scenario of (**a**) thermal and (**b**) electricity.

It is possible to notice that the energy efficiency strategies allow for reductions in the thermal and electricity consumption by 36.9% and 72.3%, respectively. In terms of the annual energy request per unit of heated surface, from ante-operam to post-operam, there is a reduction from 64.20 kWh/m^2 to 40.51 kWh/m^2. Regarding the electricity, the reduction is from 65.45 kWh/m^2 to 18.10 kWh/m^2.

In particular, it is possible to analyse that the interventions on the external walls, roof insulation, sun protection, and the optimization of the plant management can have a significant annual heating reduction from 445,638 kWh to 275,082 kWh (without considering the amount needed to heat the domestic water that is the same value of 16,635 kWh for the ante- and post-operam scenarios), that corresponds to energy savings of 38.3%. In the cooling improvement scenario, there was the possibility to change the cooling machine with a higher efficiency one that brings an electricity reduction for cooling from 187,393 kWh to 104,491 kWh, that corresponds to energy savings of 44.2%.

The use of LED lamps, instead of the fluorescent ones present in the ante-operam scenario, can reduce the electricity demand from 254,720 kWh to 101,350 kWh, that corresponds to energy savings of 60.2%.

As shown in Figure 5b, the implemented PV plant can produce an annual electrical power of 104,685 kWh that can bring the annual electricity demand without PVs of 235,041 kWh to 130,356 kWh considering this technology.

The GHG emissions from ante-operam to post-operam are summarized in Table 1. It is possible to notice that the GHG emissions are about 305.4 tCO_2 for the ante-operam and 113.9 tCO_2 for the post-operam. The energy efficiency strategies can reduce the GHG emissions by 62.7%.

Table 1. GHG emissions for ante- and post-operam scenarios.

Fuel Used	Electricity	Natural Gas	Solar
ante-operam percentage usage (%)	50.5	49.5	0.0
post-operam percentage usage (%)	24.7	55.4	19.9
ante-operam consumption (kWh)	471,313	462,274	0
post-operam consumption (kWh)	130,355	291,717	104,685
ante-operam GHG emission (tCO_2)	222.4	83.0	0
post-operam GHG emission (tCO_2)	61.5	52.4	0

4. Conclusions

A significant portion of the historical buildings that make up Europe's built heritage have a significant capacity for energy savings. Social policy is typically opposed to energy retrofits because it is concerned about damaging archaeological or cultural sites. Contrarily, there are a variety of approaches to energy efficiency that may be used with historic structures while also retaining the region's architectural constraints. This study's objective was to evaluate the viability of retrofitting a historic structure located in an area with limited architectural options by examining the technical, economic, budgetary, and environmental viability of each retrofitting plan.

A historical building in Rome was used to analyse the energy efficiency of seven different types of refurbishment interventions with minor impacts on the historical value in order to achieve energy savings and a reduction in GHG emissions.

A commercial tool named RETScreen was used to build a reliable and accurate model of the building energy use that was calibrated by a comparison with the readings from bills of electricity and natural gas consumption with a resulting discrepancy in the thermal and electricity use of −2.2% and +3.0%, respectively. The built model can be used as an optimum tool to analyse different kinds of energy efficiency solutions for the refurbishment of building envelopes and systems.

The results of this study show that a relevant reduction in the energy use and the GHG emissions can be conducted also for historical buildings that usually are not the object of energy efficiency technologies due to the architectural constraints involved with the building or in the surrounding areas. For the historical building taken into account, the relevant potential of this kind of building in terms of saved energy and GHG emission reductions were highlighted. As a matter of fact, reductions of 36.9% and 72.3% for electricity and natural gas were reached through the adoption of interventions on the building envelope, the optimization of the HVAC management, and the introduction of low-visual-impact PVs. Furthermore, a total reduction of 62.7% for GHGs was calculated for the post-operam scenario compared to the actual one.

Future development of the present work will be to implement the retrofitting strategies on the case study and evaluate the effective energy, environmental, and financial data in order to compare with the hypothesized scenarios. With this future study, it will be possible to evaluate the goodness of the methodology adopted in the present work focusing the attention into the numerical model errors achieved. Furthermore, it will be possible to implement the numerical model with other dynamic simulation tools.

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